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Neogene Paleontology in the Northern Dominican Republic

1. Field Surveys, Lithology, Environment, and Age

by

John B. Saunders, Peter Jung,
and Bernard Biju-Duval

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NEOGENE PALEONTOLOGY IN THE NORTHERN DOMINICAN REPUBLIC
1. Field Surveys, Lithology, Environment, and Age

By

John B. Saunders,[1] Peter Jung,[1] and Bernard Biju-Duval[2]

ABSTRACT

This is the first in a series of papers on the Neogene fossiliferous sediments exposed along the south flank of the Cibao Valley west of the city of Santiago, Dominican Republic. Part One provides field data and stratigraphic and environmental conclusions as a framework for subsequent, detailed faunal and floral studies. Later refinement and alteration in the conclusions is to be expected.

Field work carried out in 1978, 1979 and 1980 concentrated on the Río Gurabo and Río Cana sections while other rivers as far east as the Río Yaque del Norte were studied in less detail. The work has provided a number of parallel transects through sediments ranging in age from Miocene to middle Pliocene, giving an insight into the development of the south flank of the Cibao trough.

The 887 samples collected in the field have been sorted and distributed for macrofossil and microfossil analysis.

The classical subdivision into formations has been found to be difficult to use in the field, because each unit can be reliably differentiated only in its type area. We have stabilized the fourfold subdivision of the Miocene and Pliocene rocks as far as possible in an appendix. The stratigraphy of this time interval is as follows:

Mao Formation: maximum thickness exposed, 625 m

Age: late early Pliocene to middle Pliocene. Upper part of *Globorotalia margaritae* Zone to upper part of *Globorotalia miocenica* Zone (based on planktic foraminifera) and NN14 Zone to NN15 Zone or above (based on calcareous nannofossils).

Gurabo Formation: maximum thickness, 420 m

Age: late late Miocene to early Pliocene. ?*Globorotalia humerosa* Zone to upper part of *Globorotalia margaritae* Zone (based on planktic foraminifera) and NN11 Zone to NN13 Zone (based on calcareous nannofossils).

Cercado Formation: maximum thickness, 275 m

Age: late Miocene. NN11 Zone (based on calcareous nannofossils).

Baitoa Formation (recognized only in the type area): thickness measured, 75 m

Age: in the interval from late early to early middle Miocene (based on ostracode and molluscan evidence).

In both Río Cana and Río Gurabo, the sediment sequences start with shallow-water conglomerates, sands and silts and progress to highly calcareous silts in which beds of coral are frequent but in most instances suggest transport on an unstable slope. The Río Gurabo has a deeper-water, more open-marine facies than is seen in the Río Cana. In the Río Cana is found a thick sequence (340 m) of coral-rich limestone. This facies is not seen in the Río Gurabo, where the time equivalents seem to be silts interbedded with much thinner coral debris beds, conglomerates and pebbly sands. In both sections the highest outcrops are of sands and conglomerates, with conspicuous channeling in those of the Río Gurabo. The general tendency is for deeper-water environments to occur upsection in both rivers, but this has to be seen in the context of increasing distance into the trough. The marked instability of the north flank of the Cordillera Central in the Neogene is evident from the sedimentation patterns in the two river sections.

In the Río Yaque del Norte, fossiliferous silts (Baitoa Formation) overlying a thick sequence of conglomerates of the Tabera Group are believed to represent a time interval not seen in the Río Gurabo and Río Cana. A thick limestone interval occurs higher in the sequence, but this appears to be of latest Miocene age, unlike that seen in the Río Cana.

In the Río Mao, Maury's Bluffs 1, 2 and 3 were re-collected.

RESUMEN

Este es el primero de una serie de artículos sobre los sedimentos fosilíferos del Neógeno expuestos a lo largo del flanco sur del Valle de Cibao, al oeste de la ciudad de Santiago, en la República Dominicana. El suministra datos de campo y conclusiones estratigráficas y ambientales, como un cuadro general para subsecuentes estudios detallados de la fauna y la flora. Posteriores precisiones y algunas alteraciones en las conclusiones, pueden ser esperadas.

Los trabajos de campo, llevados a cabo en 1978, 1979 y 1980, se concentraron sobre los perfiles expuestos en los ríos Gurabo y Cana, mientras otros ríos, tan lejanos al este como el río Yaque del Norte, fueron estudiados con menos detalle. El trabajo ha proporcionado un número de transectos paralelos a través de sedimentos que varían en edad, desde el Mioceno al Plioceno medio. Ellos ofrecen una visión del desarrollo del flanco sur del graben de Cibao.

Las 887 muestras colectadas en el campo, han sido clasificadas y distribuídas para estudios macro- y microfósiles.

La clasica subdivisión en formaciones se ha encontrado que es difícil de usar en el campo, porque cada unidad puede ser seguramente diferenciada sólo en su área tipo. Los autores han establecido, tanto como ha sido posible, la cuádruple subdivisión de las rocas del Mioceno y del Plioceno en un apéndice. La estratigrafía de este intervalo de tiempo es como sigue:

---

[1] Naturhistorisches Museum Basel, Basel, Switzerland.

[2] Institut Français du Pétrole, Rueil-Malmaison, France, and Institut Français de Recherche pour l'Exploitation de la Mer, Paris, France.

Formación Mao: espesor máximo expuesto, 625 m

Edad: Plioceno temprano tardío a Plioceno medio. Parte superior de la Zona *Globorotalia margaritae* a la parte superior de la Zona *Globorotalia miocenica,* sobre la base de foraminíferos planctónicos, y Zona NN14 a Zona NN15, o más arriba, sobre la base de nannofósiles calcáreos.

Formación Gurabo: Espesor máximo, 420 m

Edad: Mioceno tardío tardío a Plioceno temprano. Zona *Globorotalia humerosa* (?) a la parte superior de la Zona *Globorotalia margaritae,* sobre la base de foraminíferos planctónicos, y Zona NN11 a Zona NN13, sobre la base de nannofósiles calcáreos.

Formación Cercado: Espesor máximo, 275 m

Edad: Mioceno tardío. Zona NN11, sobre la base de nannofósiles calcáreos.

Formación Baitoa (reconocida solamente en la región tipo): Espesor medido, 75 m

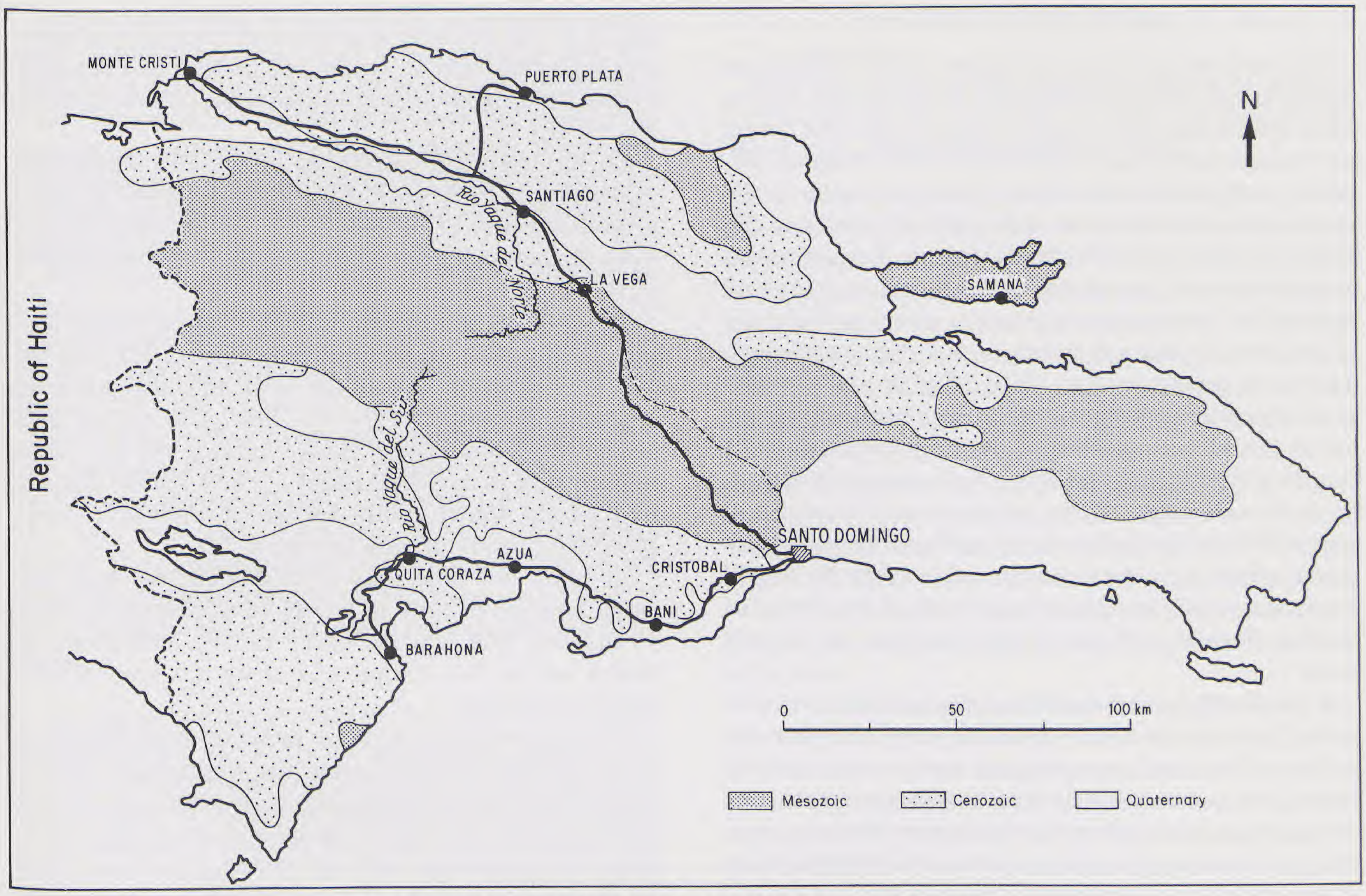
Edad: en el intervalo Mioceno temprano tardío a Mioceno medio temprano, sobre la base de moluscos y ostrácodos.

Las secuencias de sedimentos expuestas en los ríos Cana y Gurabo comienzan con conglomerados, arenas y limos suavemente cementados de aguas poco profundas, y progresan a limos altamente calcáreos poco cementados, en los cuales son frecuentes capas de corales, pero en la mayoría de los casos sugieren transporte en un declive inestable. La secuencia del río Gurabo se depositó en aguas más profundas; presenta una facies marina más abierta que la que se observa en el río Cana. En el río Cana hay una potente secuencia (340 m) de caliza rica en corales. Esta facies no ha sido encontrada en el río Gurabo, donde el tiempo equivalente parece estar representado por capas de limos poco cementados, intercalados con capas mucho más delgadas de detritos coralinos, conglomerados y areniscas guijarrosas friables. En ambos perfiles los afloramientos superiores son de arenas poco cementadas y conglomerados, con facies de canales en los del río Gurabo. La tendencia general es que los ambientes de aguas más profundas se encuentren en las secciones superiores de ambos ríos; pero esto tiene que ser visto en el contexto del incremento de la distancia dentro del graben. La marcada inestabilidad del flanco norte de la Cordillera Central en el Neógeno, es evidente en los patrones de sedimentación de las secciones de ambos ríos.

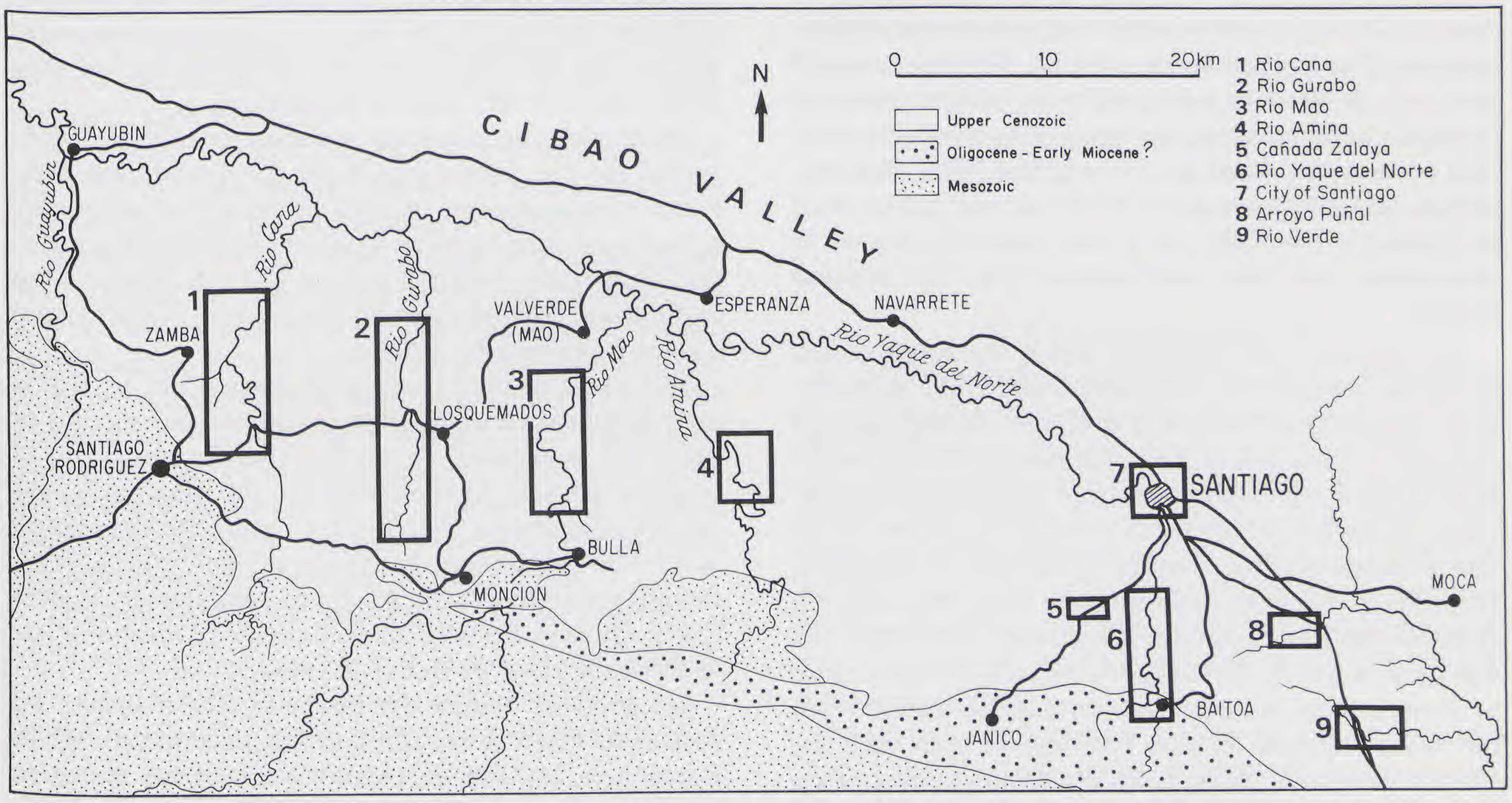
En el río Yaque del Norte, los limos fosilíferos poco cementados de la Formación Baitoa, los cuales sobreyacen a la potente secuencia de conglomerados del Grupo Tabera, se cree representan un intervalo de tiempo que no se reconoce en los perfiles de los ríos Gurabo y Cana. En la parte superior de la secuencia se halla una potente caliza, pero esta parece ser de edad Mioceno más tardío y es diferente de esa encontrada en el río Cana, la cual es de edad Plioceno.

En el río Mao, las escarpas 1, 2, y 3 de la Dra. Maury fueron nuevamente colectadas.

Text-figure 1.—Map of the Caribbean area, showing some of the more important Neogene molluscan localities.



Text-figure 2.—Geological sketch map of the Dominican Republic.



Text-figure 3.—Geological sketch map of the Cibao Valley, northern Dominican Republic, showing areas from which samples for this project were collected. More detailed maps of areas 1 (Text-fig. 15), 2 (Text-figs. 4, 5), 3 (Text-figs. 29, 30), 4 (Text-fig. 34), 5 (Text-fig. 36), 6 (Text-fig. 21), 7 (Text-fig. 22), 8 (Text-fig. 37), and 9 (Text-fig. 38) show geographic positions of most NMB, and some TU, USGS, and other collecting localities.

INTRODUCTION

The richness of Cenozoic faunas in the Dominican Republic has attracted attention since the first collections were made more than a century ago. Our group has become particularly interested in the Neogene sediments exposed in the Cibao Valley, situated in the northwest of the Dominican Republic (Text-figs. 1–3). There are few places in the Caribbean Region where macrofaunas of this age are so diverse and also so well exposed in continuous sequences, allowing close examination of total assemblages and their relation to paleoenvironment and to time. Though much earlier work has been published, these rich faunas have yet to be placed in a modern time and environmental framework. If this can be done, the results should then be usable elsewhere in the region, to assist in an understanding of its more recent geologic history. With this in mind, a group of us planned to apply the highly successful, multi-disciplinary approach of the Deep Sea Drilling Project, and out of this was born the present study.

A small field party was formed to measure sections and collect samples. The material, amounting in total to about five tons, was shipped back to the Natural History Museum in Basel where it was processed, sorted and shipped to interested specialists in many institutions. Their results will be submitted for publication in the *Bulletins of American Paleontology*.

This first paper in the series gives as much background data as possible at this stage, to act as a framework for the detailed faunal studies. Though it would obviously be wiser to wait until more results have been produced before making too many statements, it is now that preliminary findings are required. The interpretations and inferences given in the present paper must be viewed in this light. At a later stage it is hoped to summarize and draw conclusions from the detailed studies.

We planned our approach using the unpublished geological maps of the Dominican Seaboard Oil Company produced in 1943 on a scale of 1:40,000. Reconnaissance of the area was carried out in 1977, at which time contact was made with Ing. Nelson Gil Gil, director of the Department of Geology and Mines in the Universidad Católica Madre y Maestra in Santiago, Dominican Republic, and all later work was done in close cooperation with that institution. Our field work was done in 1978, 1979 and 1980 during a total period of three months. Finance was provided by a grant from the Swiss National Science Foundation with vital additional support coming from the Institut Français du Pétrole (IFP) in Rueil-Malmaison. This support included the provision of a survey team that made it possible to map the Gurabo and Cana rivers (Text-figs. 4, 5, 15), to locate accurately the positions of samples collected, and to obtain the elevations necessary for the construction of the stratigraphic columns (Text-figs. 6, 16).

Of the left bank tributaries of the Río Yaque del Norte that provide good dip traverses across the Neogene succession (Text-fig. 3), the Río Gurabo constitutes the best standard. We spent our 1978 field season in this river.

In 1979, we worked laterally from our reference section in the Río Gurabo spending most of the time in the Río Cana 10 km to the west, but also working eastward to sample in the Río Mao, Río Amina and in the Río Yaque itself. While working the Río Mao we were able to re-collect Bluffs 1, 2 and 3 made famous by Carlotta Maury. Time restrictions allowed a comprehensive study of only the Río Cana.

In 1980, our final year of field work, we used our small amount of time to complete some survey work in the Río Mao and to make further collections at Baitoa on the Río Yaque, and along this river northward to Santiago.

The present paper makes it apparent how difficult it is to correlate laterally using the established formations. Each can be recognized in its type area, as one might expect, but lateral facies changes make correlation of formational tops and bottoms from one river to the next hazardous. The names Mao, Gurabo and Cercado formations can be used in the Río Gurabo, with less certainty in the Río Cana and possibly as far east as the Río Mao. Outside that area we feel that subdivision at this stage is conjectural.

When planning our study we tried to estimate thicknesses for the formations from the Dominican Seaboard maps and came up with values of the same order as had been used by other workers (Butterlin, Ramírez, and Hoffstetter, 1956). Thus we had maxima of: Mao Formation, 500 m; Gurabo Formation, 1000 m; and Cercado Formation, 1000 m.

The value of the survey work carried out by IFP is now apparent as we have measured a total section of only 900 m exposed in the Río Gurabo and 1200 m in the Río Cana. In these sections the maxima would be: Mao Formation, 625 m (Río Cana until the section is covered by alluvium in the lower part of the river)—including 340 m of Mao Adentro Limestone in the Río Cana; Gurabo Formation, 420 m (Río Gurabo); Cercado Formation, 275 m (Río Cana).

On the Río Yaque del Norte south of López we measured 55 m of section that we place in the Baitoa Formation, but this represents a minimum thickness for this unit.

The following methods were used to plot samples in the field.

Before leaving Basel, the 1:50,000 topographic sheets were photographed as color transparencies and enlarged to a scale of 1:5000. The relevant river sections were then traced off, copies were made and these were used as our field sheets. Wherever possible, these were later replaced by surveyed sheets produced by IFP, also at a scale of 1:5000. The accuracy of the more important maps and columns is as follows.

Río Gurabo.—Map (Text-fig. 4) constructed by reduction to 1:10,000 of the IFP theodolite survey. The samples collected in the field could be placed accurately by this means on both map and column and the thickness of the total section calculated (Text-fig. 6).

Río Cana.—Map (Text-fig. 15) downstream from the horseshoe bend at NMB locality 16984 surveyed by IFP as in the Río Gurabo. Upstream from this point, the map was taken from the 1:50,000 topographic sheets. The measurement of thicknesses for the column (Text-fig. 16) are from the survey down to the level of the *Arca* beds. Below that, some estimations had to be made.

Río Yaque del Norte.—Maps (Text-figs. 21, 22) were enlarged from the 1:50,000 topographic sheets. The column for the whole river (Text-fig. 24) was calculated using dips and strikes measured in the field plotted over distances calculated from the 1:50,000 map. The column at López (Text-fig. 25) was measured using compass, tape and measuring rod.

Río Mao.—Map (Text-fig. 29) was enlarged from the 1:50,000 topographic sheets. The maps and columns of Text-figures 30, 31, and 32 were measured using compass, tape and rod.

Río Amina.—Map (Text-fig. 34) was enlarged from the 1:50,000 topographic sheets. Some isolated samples on this river are not accurately located.

We shipped back to Basel a total of approximately 300 samples for macrofossil study (see Appendix 3) and 500 for microfossil study (see Appendix 2). Wherever possible, the two sets are from the same horizons to allow complete faunal analysis of contemporaneous populations which, in turn, are linked to varying lithologies. A list of paleontologists involved in the project at the time was given in Saunders *et al.* (1982); there have been some changes since then with the number now standing at around 50 individuals.

The make-up of the field parties was as follows:

1977. Reconnaissance by J. Saunders in cooperation with Prof. John Weaver of Puerto Rico.

1978. B. Biju-Duval, W. van den Bold, A. Chartier, P. Jung, C. Meynot, J. Saunders.

1979. B. Biju-Duval, W. van den Bold, A. Chartier, A. Eva, J. Geister, P. Jung, A. Mascle, J. Saunders.

1980. A. Chartier, J. Geister, P. Jung, A. Mascle, J. Saunders.

Field Excursion for the Ninth Caribbean Geological Conference led by J. Geister, P. Jung, J. Saunders (see Biju-Duval, Jung, and Saunders, 1980).

The main responsibilities within the Project are as follows. Bernard Biju-Duval has produced the surveyed maps and columns at IFP. Macrofossil studies are being coordinated by Peter Jung, who has sorted and classified the various fossil groups and distributed them to specialists for study. John Saunders is coordinating microfossil studies, and has produced the dating on planktic foraminifera while Carla Müller has provided nannofossil dating, Willem van den Bold the ostracode results, and Jacques Butterlin the dating of the Tabera limestones, based on larger foraminifera. The responsibility for the text of the present paper has largely fallen to John Saunders but the three authors would like to mention again their gratitude to all those listed in the Acknowledgments for their important contributions.

It is normal practice in *Bulletins of American Paleontology* to give author and date for all taxa. In the present paper we are using many of the taxa in a rather broad way, particularly at the generic level. For this reason, we feel that it would be misplaced accuracy to give a citation in many instances. Therefore, such references are confined to the few species that we use in a definitive fashion. A specific example of this broad usage is the expression "menardiform Globorotalias". Further work will be done on this plexus of forms but, at present, they have been found useful *as a group*, particularly in respect to the ratio of right-coiled to left-coiled individuals.

ACKNOWLEDGMENTS

In the Dominican Republic we would like to acknowledge the support received from Monsignor Agripino Núñez C., and Ing. Nelson Gil Gil of the Universidad Católica Madre y Maestra. Falconbridge Dominicana, under its manager Mr. Bill Dales, provided generous assistance with transport while Ing. Romeo Llinas of the Ministry of Mines was most helpful. Ing. José Hungria, director of the Instituto Geografico Universitaria made it possible for us to purchase topographic maps.

Important contributions to the present paper have come from Dr. Carla Müller (calcareous nannofossils), Dr. Jörn Geister (corals), Dr. Willem van den Bold (ostracodes), Dr. Jacques Butterlin (larger foraminifera), and Dr. Enrique Gonzalez (palynology).

Table 1.—Stratigraphy of the Cibao Valley, northern Dominican Republic, as interpreted by authors of pertinent papers.

age \ authors	Maury 1917 b	Maury 1919	Cooke 1920 1921	Vaughan et al. 1921	Maury 1929 1931	Weyl 1940	Bermudez 1949	Butterlin 1954	Ramirez 1956	Weyl 1966	van den Bold 1968	van den Bold 1969	van den Bold 1972	Bowin 1975	Seiglie 1978	Dorreen 1979	Vokes 1979	present paper
Pleistocene																		
Pliocene												Mao Gurabo	Mao Gurabo	Mao	Mao Gurabo			? Mao
Miocene late	*Sconsia laevigata*				Caimito		Mao	Mao		Mao	Mao	Cercado		Gurabo		Mao Gurabo	Gurabo and Cercado	Gurabo Cercado ? ?
Miocene middle		Gurabo *Sconsia laevigata*	Valverde clay Mao Adentro limestone Gurabo	Mao clay Mao Adentro limestone Gurabo	Gurabo	Mao clay Mao Adentro limestone Gurabo	Gurabo	Gurabo	Mao Gurabo	Gurabo	Gurabo		Cercado (Baitoa)		Cercado	Cercado Cevicos	?	
Miocene early	*Aphera islacolonis*	Cercado *Aphera islacolonis*	Cercado Baitoa Bulla	Cercado Baitoa	Cercado	Cercado	Cercado Baitoa Bulla	Cercado	Cercado	Cercado	Cercado		Tabera	Cercado		Tabera	Baitoa	Baitoa ? ?
Oligocene			Cevicos limestone Tabera	Cevicos limestone Tabera		Cevicos-Kalk Tabera	Tabera	Trinchera Sombrerito Tabera		Villa Trina Tabera	Tabera			Tabera			Tabera	Tabera

Aid has also been sought from Dr. Hans Bolli and Dr. Anthony Eva (foraminifera), Dr. Katharina Perch-Nielsen (calcareous nannofossils), and Dr. William Macdonald and Dr. William Lowry (paleomagnetics). Dr. Macdonald has collected his own samples along the Río Gurabo for paleomagnetic studies and it is expected that he will continue this work and publish the results separately.

Drafting of the foldouts was undertaken by the Institut Français du Pétrole in Rueil-Malmaison, who also paid half the cost of their printing. In Basel we have been fortunate to have the facilities of the Natural History Museum, including aid in preparation of the manuscript and figures by Messrs. Urs Marrer, René Panchaud and Wolf Suter.

We repeat our gratitude to the Swiss National Science Foundation for their grant No. 2.646-0.76, and to the Institut Français du Pétrole for their great contribution of both expertise and finance.

EARLIER PALEONTOLOGIC AND STRATIGRAPHIC STUDIES

In the following paragraphs we refer to the majority of paleontologic and stratigraphic papers that have been written on the Neogene of the Cibao Valley. The text discusses those papers that give new information based on material collected, while Table 1 gives the stratigraphic conclusions of most of these authors and also of others, a number of whom only made compilations of earlier work. All are included on the table to show the development of thinking from 1917 to the present day.

The earliest authors reporting on fossils from the Neogene of the Northern Dominican Republic include G. B. Sowerby II (1850) in Moore (1850), Moore (1853) and Lonsdale (1853), both in Heneken (1853), who discussed a number of localities. Some of the molluscs described by G. B. Sowerby II (1850) were later revised by Pflug (1961). In 1873 Gabb described a large number of molluscan species, but he gave neither illustrations nor locality information. This gap was partly filled by Pilsbry (1922), who revised the species described by Gabb (1873), and also those described but not figured by Pilsbry and Johnson (1917). Maury (1917a, 1917b, 1919, 1929, 1931) added a great deal to the knowledge of the Neogene molluscs and their stratigraphic occurrence. The aims of her expedition to the Dominican Republic in 1916 read very much like those of our own project. Her low-key account of the difficulties and dangers of the trip is a classic of understatement and well worth reading (Maury, 1917a).

It may be noted at this point that Maury (1931) assigned a late Miocene age to her Caimito Formation. This assignment infers that her Caimito beds by necessity overlie her Cercado and Gurabo formations (Maury, 1929). However, there is some confusion here as her measured sections in the 1917b paper make it fairly clear that she would place the *Arca* beds, which she later included in her Caimito Formation, low in the Gurabo Formation and perhaps also including some of her original Cercado Formation concept. This is logical as the Caimito outcrops are well down in the overall Río Cana Section (Text-fig. 15 of the present paper).

The most important stratigraphic work on the Cibao Valley formed a part of the study undertaken by T. W. Vaughan and his associates of the U.S. Geological Survey in 1917 which is published in detail in Vaughan *et al.* (1921). Particularly relevant is the chapter on stratigraphy and geologic history by W. Cooke and on Tertiary and Quaternary stratigraphic paleontology by T. W. Vaughan and W. P. Woodring. The latter contains the first comprehensive lists not only of molluscs but also of corals and foraminifera, the last of which were taken from the work of Cushman (1919). This stratigraphic work formed the basis for all later studies.

The USGS collecting stations are, wherever possible, plotted on the maps provided with the present paper (see also Appendix 5).

An important field study was undertaken by Dominican Seaboard Oil Company leading to the production in 1943 of the 1:40,000 manuscript maps that we used in our planning. Samples collected by oil company geologists, particularly C. F. Dohm, formed the basis for a monograph on smaller foraminifera by Bermudez (1949) and on ostracodes by Bold (1968).

The papers by Ramírez (1950, 1956) merely list and figure some of the species already described from the Cibao Valley.

A series of eight colored geologic maps at a scale of 1:250,000 was published as an atlas (Zoppis, 1969). This compilation contains the work of many earlier geologists and, with its pages of explanatory notes, forms a useful basis for later work.

Our own collecting was preceded by and partly overlapped the collecting activities of Emily and Harold Vokes of Tulane University, New Orleans, Louisiana, U.S.A. The Vokes' collecting stations are plotted as TU localities on our maps (see also Appendix 4). Some age assignments based on their collections were given by Vokes (1979).

THE RIVER SECTIONS

Río Gurabo

General

We started our field work in the Río Gurabo, because previous information suggested that this river would provide the best reference section. As a matter of logistic convenience, the survey and sampling was begun at a central access point (Los Quemados). The numbers generally run from that point down river to the top of the section and then up river to the lowest part of the section, including the Río Gurabito tributary.

For the section down river from Los Quemados, it was possible to use a 4-wheel-drive vehicle along a difficult track that crosses and recrosses the river and finally joins the road from Mao to Guayubín. During or after heavy rain, this track is likely to be impassable. The southern part is reached from footpaths, and finally from a track running from the Mao to Moncíón road to the river at Monte Higuero.

To examine the section in its entirety, long stretches can only be reached on foot, making it difficult to bring out large volumes of samples.

The work took three weeks, during which time approximately 348 samples were collected for microfossils and for lithologic study, and 137 samples were collected for macrofossils.

Lithology

Tabera Formation.—This unit was not studied or sampled in detail. The upper part of the exposed section is predominantly limestone, with an average dip of 40° towards the east. Interbedded subordinate conglomerates, coral rubble beds and shell beds were noted. The limestones often have abundant larger foraminifera and miliolids. They are certainly rich in coral and algal colonies, but these are not always easy to identify due to heavy recrystallization of the whole rock. Palmer (1979) has erected the name Moncíón Limestone as a formation within the Tabera Group.

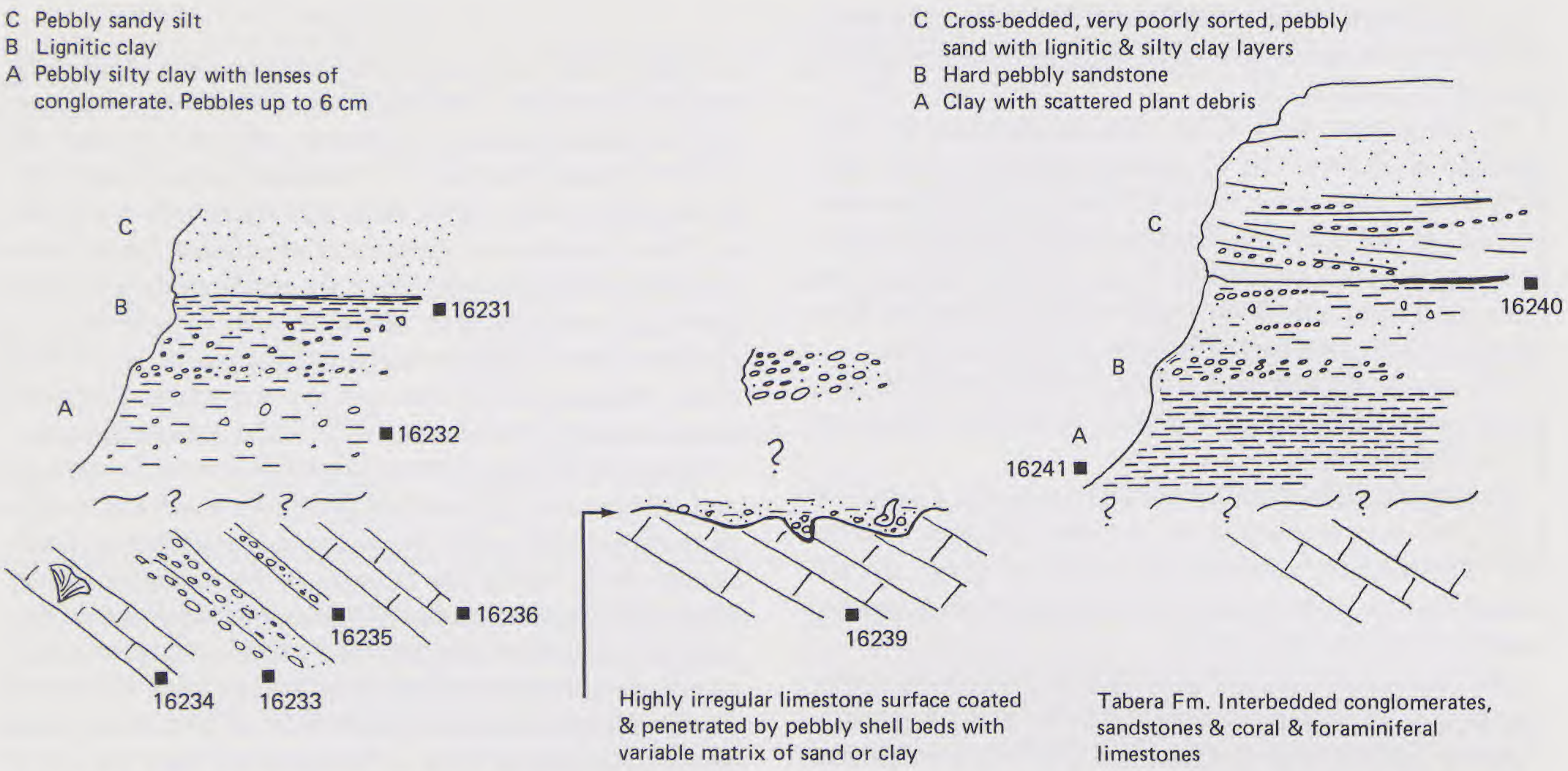
Below more than 200 m of predominant limestones and calcarenites, the section becomes much more conglomeratic, with only subordinate coralliferous limestones. Beds which are thought to be stratigraphically lower are exposed in the Río Gurabito and higher upstream in the Río Gurabo, where thick, massive, polymictic conglomerates rest directly on green schists of the Cordillera Central (NMB loc. 16254), or perhaps are faulted against them. The predominant red color of the basal conglomerates is noticeable and suggests that they would be placed by Palmer in his Inoa Conglomerate.

Tabera/Cercado contact (Text-fig. 7).—The actual contact between the Cercado Formation and the underlying Tabera Formation is rarely exposed. Where an eroded Tabera surface is seen, it shows considerable relief and is almost certainly karstic, sometimes exhibiting autobrecciation (NMB loc. 16239). The surface is here penetrated by pebbly shell beds occupying solution hollows, some of which are coated with clay.

The marked difference in dip at the unconformity shows that the older beds were faulted and folded, or at least tilted, before being eroded. This episode of active tectonics must have been important in the history of development of the Cibao trough.

Cercado Formation.—The lower part of the formation consists of sands with interbedded conglomerates and subordinate silts and clays (Text-figs. 7, 8). The dip is less than 10° towards the north. Sorting is generally poor and pebbles occur frequently in the sands and silts. The clays are often rich in plant debris and may pass laterally or vertically into lignites. Cross-bedding is very common in the sands. The beds are basically noncalcareous except around scattered shell fragments and where secondary redeposition of calcium carbonate has formed concretionary layers.

Upwards, sands and silty sands strongly predominate with minor pebbly layers and lenses. The sands are often coarse-grained and show scour structures and planar cross-bedding. Tests of *Amphistegina* are exceedingly common and are often concentrated along the crossbeds where they stand out conspicuously as



Text-figure 7.—Three sections from the southern end of the study area on Río Gurabo, showing the nature of the contact between the Cercado Formation and the underlying Tabera Formation (see Text-fig. 4, bottom). Black squares represent NMB localities collected for microfossils and lithologic analyses.

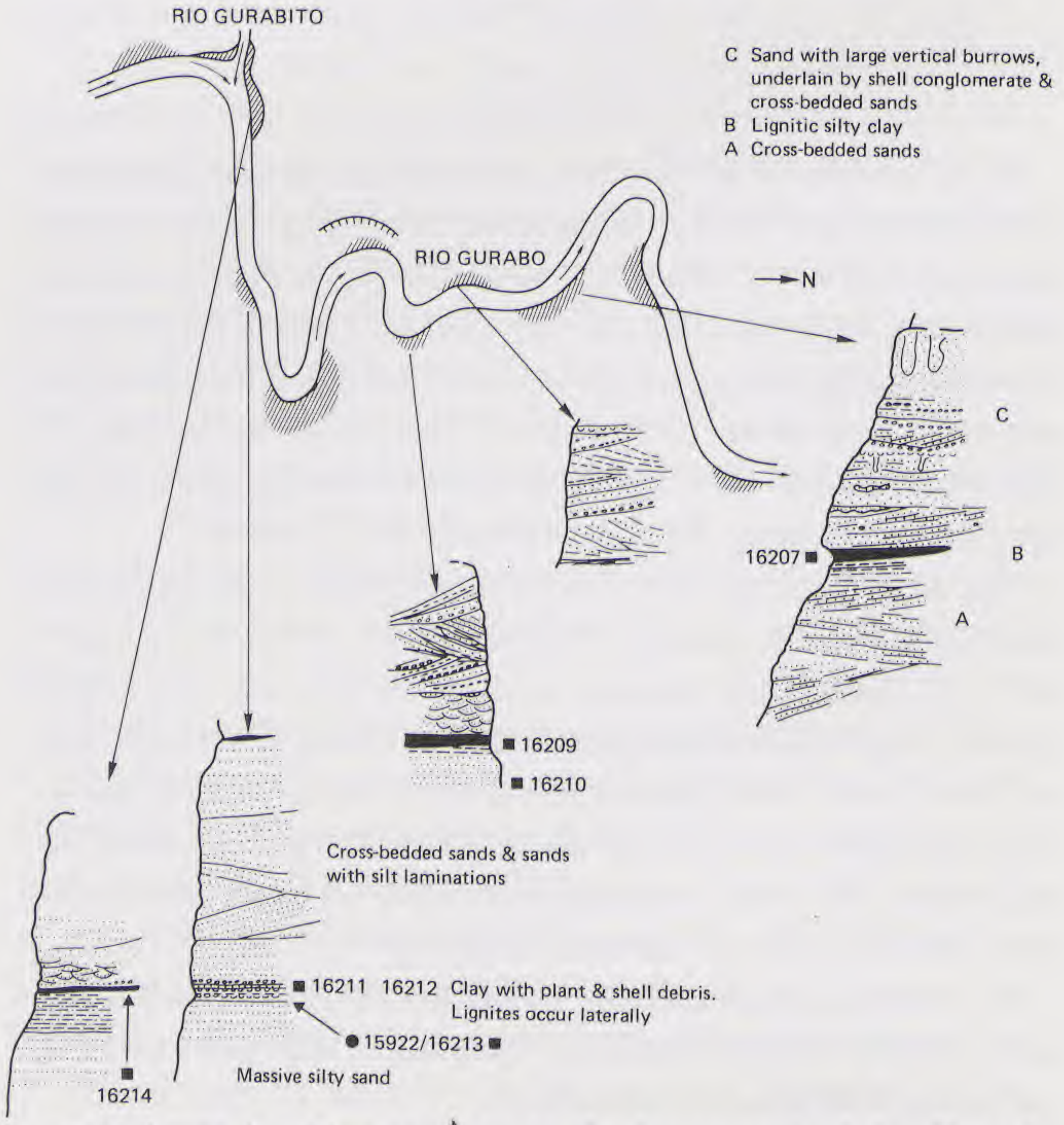
lines (Pl. 1, fig. 4). Bioturbation is intense at many levels with *Callianassa*-sized burrows and smaller ones; these are often packed with shell fragments and *Amphistegina.*

The highest level seen in the Cercado Formation is a silt packed with coral and algal debris. This may be up to nine m thick, but can also be completely cut out by overstepping of the basal Gurabo conglomerate (Text-fig. 9; Pl. 1, fig. 1).

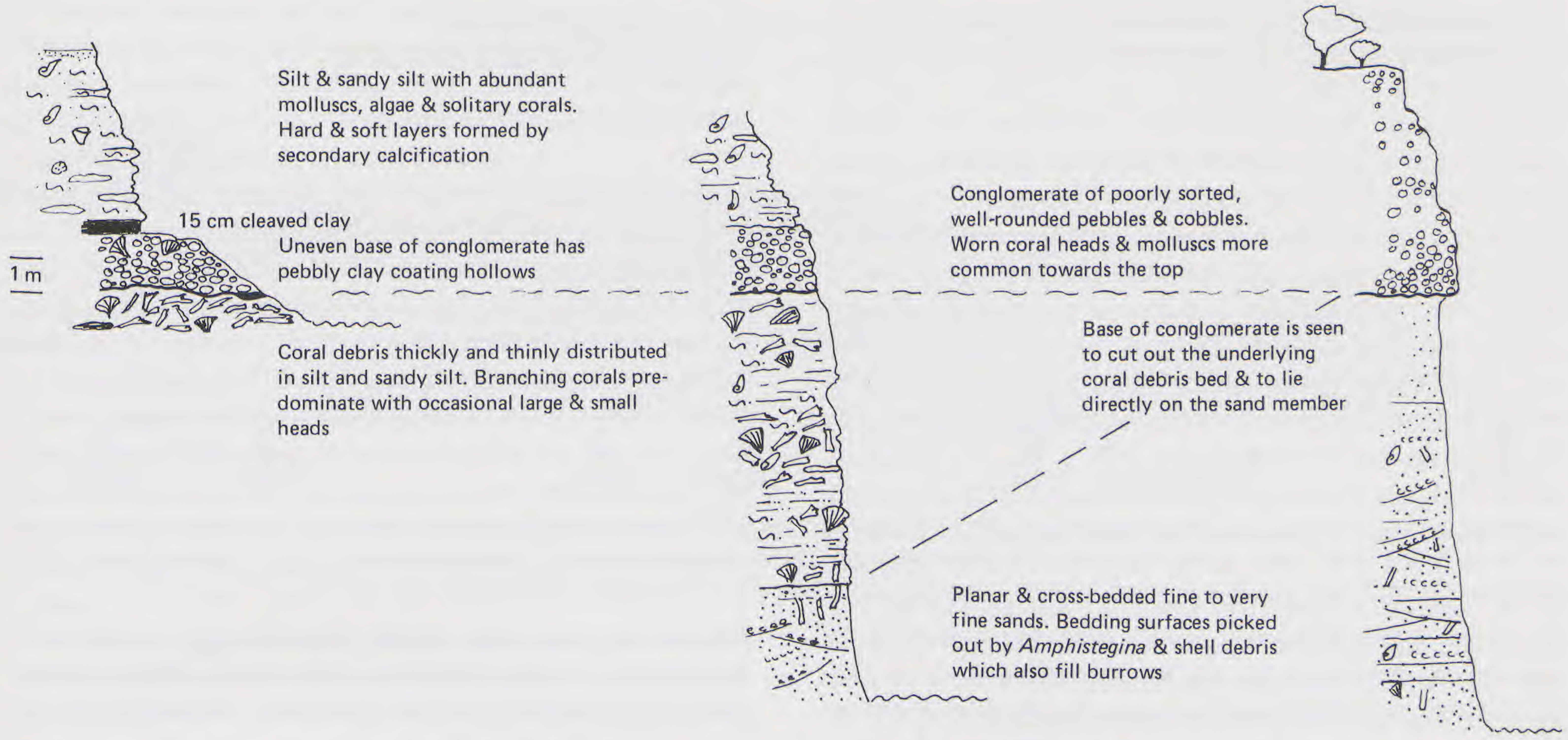
Gurabo Formation.—The basal conglomerate when seen at river level is less than two m thick, but when seen capping cliffs upstream, where it has cut out the underlying coralliferous silt, it is at least seven m thick (Pl. 1, fig. 1). The base is irregular and shows clay-lined scours filled with finer conglomerate overlain by coarser spreads of pebbles and cobbles. The components are well-rounded but poorly-sorted up to 15 cm in diameter (Pl. 1, fig. 2). The material is polymictic and apparently derived from the Cordillera Central. No examples of Tabera Limestone were seen. Poorly-preserved, scattered molluscs and coral heads are found throughout but are more common towards the top.

Above the conglomerate follow calcareous, fossiliferous silts with bedding picked out by lines of calcareous concretions. Molluscs and solitary corals are scattered throughout. The silts pass up into cross-bedded, burrowed sands similar to those seen in the Cercado Formation (Pl. 2, fig. 5).

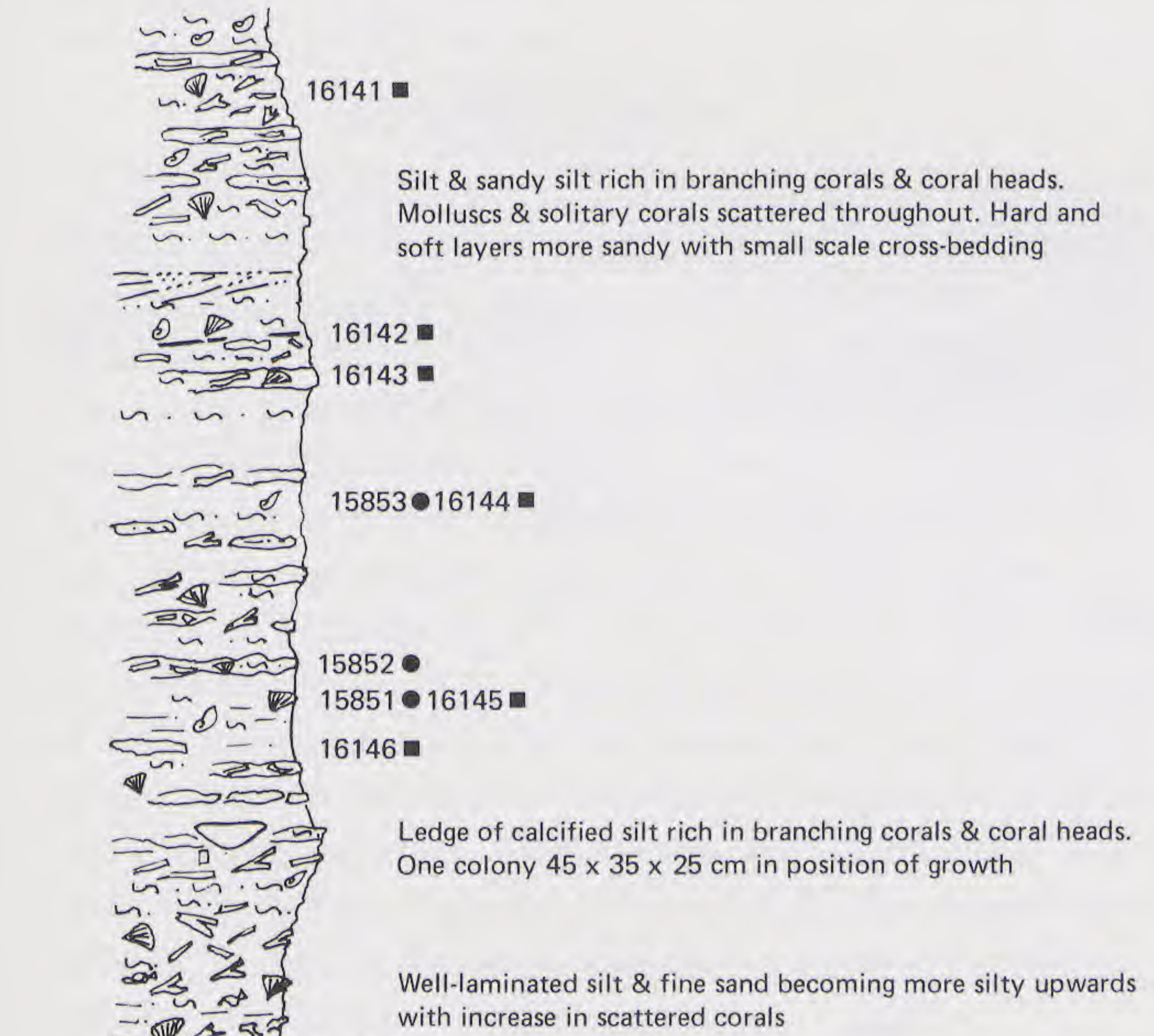
The calcareous silts and sandy silts that follow are characterized by their richness in corals, which occur in beds and as separate, scattered heads. Some corals are in position of growth while others have been transported (Text-fig. 10; Pl. 2, figs. 3, 4). At the top of the



Text-figure 8.—Five sections in the lower part of the Cercado Formation on Río Gurabo (see Text-fig. 4, bottom), showing details of sands and interbedded lignitic clays. Black squares represent NMB localities collected for microfossils and lithologic analyses; black circles represent NMB localities collected for macrofossils.



Text-figure 9.—Three sections illustrating the unconformable overstep of the basal conglomerate of the Gurabo Formation on Río Gurabo across the coral beds and sands of the underlying Cercado Formation. Figures 1 and 2 of Plate 1 illustrate this contact.

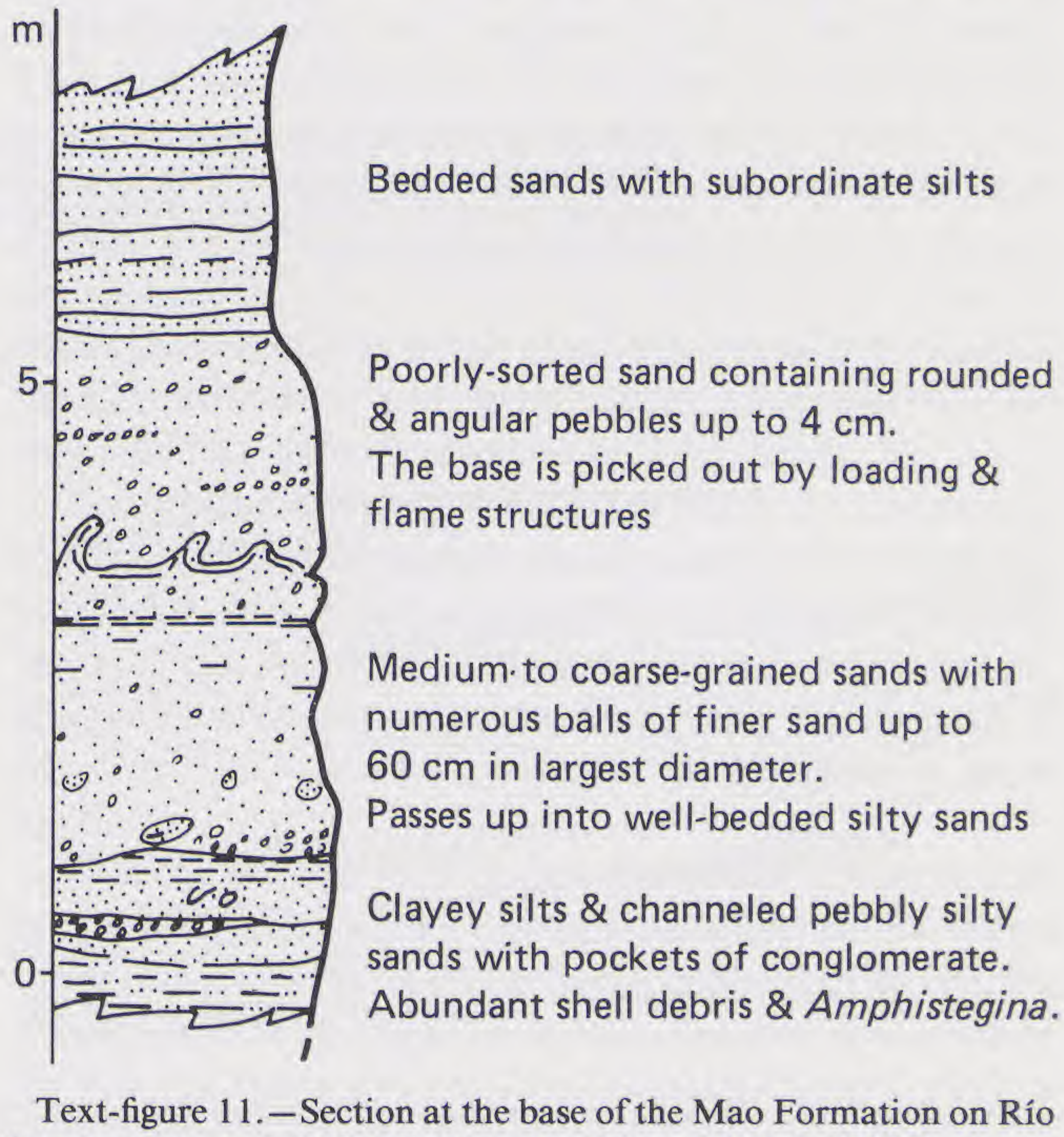


Text-figure 10.—Section in the Gurabo Formation on Río Gurabo (see Text-fig. 4, middle), showing details of coral-rich horizons exposed in a steep ravine in the cliffs on the left bank. Black squares represent NMB localities collected for microfossils and lithologic analyses; black circles represent NMB localities collected for macrofossils.

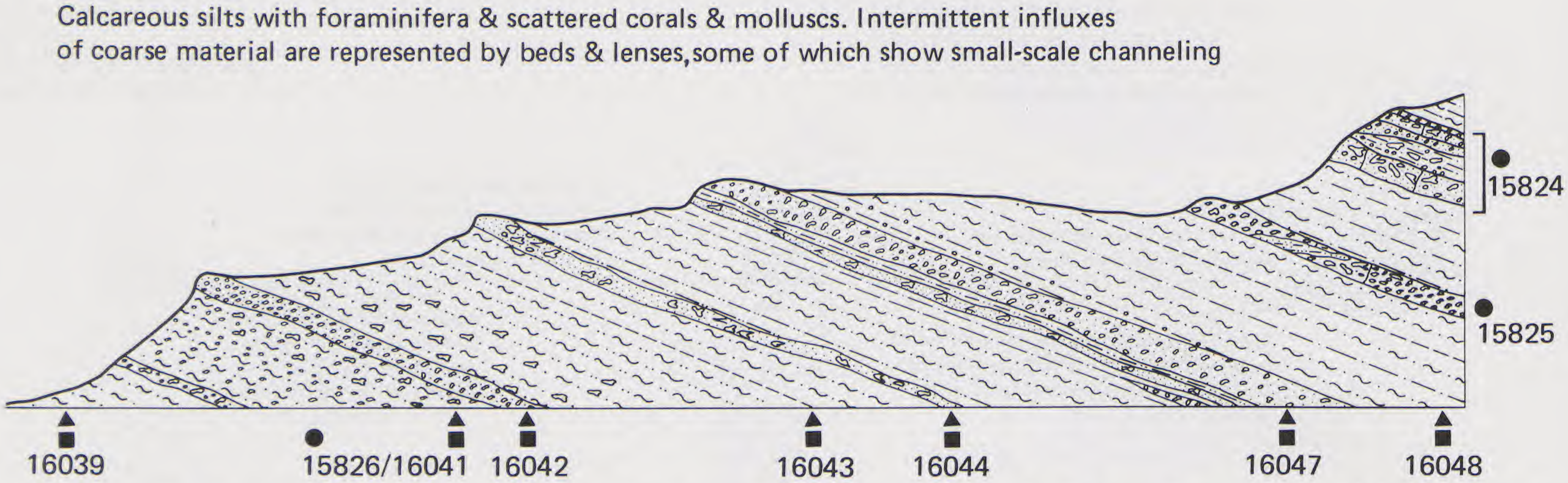
coral-rich sequence occur interbedded biostromal corals and coralliferous silts (Pl. 2, fig. 2).

Downstream from the road bridge at Los Quemados, there follows a thick section predominantly of massive, calcareous silts rich in microfossils and with molluscs scattered and in lenses. Some levels are also rich in coral debris and solitary corals.

Mao Formation.—The base of the formation is tak-



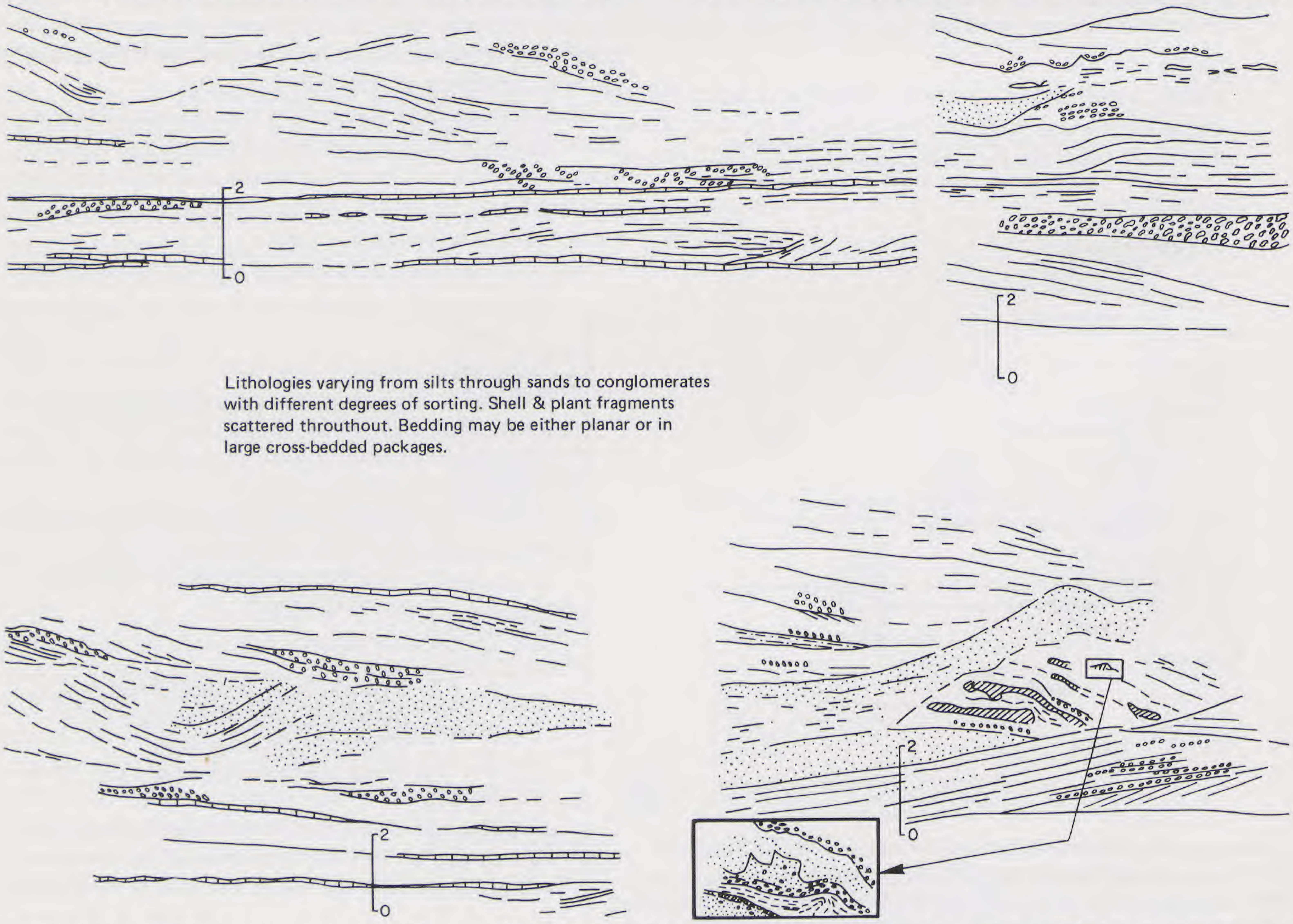
Text-figure 11.—Section at the base of the Mao Formation on Río Gurabo close to NMB collecting localities 15994 to 15999.



Text-figure 12.—Section in the Mao Formation on Río Gurabo (see Text-fig. 4, top), showing fossiliferous silts with interbedded conglomerates and coral debris beds. Black squares represent NMB samples collected for microfossils and lithologic analyses; black circles represent NMB localities collected for macrofossils; black triangles represent exact horizons collected for microfossils. See also Plate 3, figure 3.

en where predominantly sandy silts are overlain by channeled, medium- to coarse-grained sands and conglomerates showing loading and the development of flame structures; one sand bed is conspicuous for having many enclosed balls of finer sand (Text-fig. 11). Bed thicknesses alter rapidly laterally (Pl. 3, figs. 4, 5). Burrowing is not a feature at this level. The conglomerate components are less polymictic than those at the base of the Gurabo Formation.

Calcareous, clayey silts follow the basal beds. After



Text-figure 13.—Four exposures observed between NMB localities 16119 and 16122 in the Mao Formation on Río Gurabo (see Text-fig. 4, top), showing channeling, cross-bedding and slumping characteristic of the younger portions of that unit (see also Pl. 3, fig. 1).

a covered interval, calcareous silts and sandy silts occur interbedded with thin (decimetric) beds and lenses of coarser material including coral debris and pebbles (Text-fig. 12; Pl. 3, fig. 3). Some of the conglomerates show erosional bases.

Pebble beds become less important upwards where interbedded, harder and softer calcareous silts form high cliffs (Pl. 3, fig. 2). The harder layers are usually packed with coral debris while the softer layers contain a rich microfauna; molluscs are scattered throughout.

True limestone ("Mao Adentro Limestone") is poorly developed in the Río Gurabo. Shelly and pebbly limestones with corals occur as blocks in the river and in small outcrops on the slopes above, but it is difficult to know how continuous this near-reef facies was. One possibility is that this part of the section is cut out by a fault.

After an interval with almost no outcrops, a series of low cliffs expose sands, pebbly sands and conglomerates that show both large and small scale channeling (Text-fig. 13; Pl. 3, fig. 1).

Higher parts of the section are hidden under a cover of young terrace sands and gravels of the Río Yaque del Norte.

Environment

Cercado Formation.—The environment of the basal beds is shallow-marine to brackish with molluscs occurring on the karstic surface of the underlying Tabera Limestone. This is in contrast to the situation in the Río Cana where the base of the section could be nonmarine, though not necessarily of exactly the same age. The sorting is poor, suggesting varying energy levels, the higher ones being indicated by pebble layers and crossbeds (Text-fig. 8; Pl. 1, fig. 5) and the lower ones by carbonaceous clays. An internal report by G. Deroo of IFP indicates that the carbonaceous component is made up of a mixture of terrestrial vegetable matter and marine material. The presence of calcareous concretionary layers suggests that some of the shells may have been lost by solution and this is a feature throughout the whole Río Gurabo section.

As pointed out by Saunders *et al.* (1982) the lower part of the Cercado Formation is characterized by a *Larkinia–Mytilus–Melongena* mollusc assemblage, which indicates a brackish-water environment (Rutsch, 1942; Clench and Turner, 1956).

The upper half of the formation is dominated by sands, often cross-bedded (Pl. 1, fig. 4) with huge numbers of tests of *Amphistegina* along the crossbeds and infilled burrows, many of which are 3.5 to 4 cm wide and suggest those of the arthropod *Callianassa.* Molluscs as whole shells and as broken debris occur scattered and in the burrows. Many, or perhaps all of the *Amphistegina* tests have been concentrated by water movements but the preservation of many suggests that no great transport was involved. Shallow-water sand shoals are indicated, with thickets of *Thalassia* (eelgrass) probably originally present on the sea bottom. No trace of these now remain but the richness of soritid foraminifera in some samples suggests their presence at the time of deposition, as these organisms prefer to live as epizoans on eelgrass blades. The rest of the foraminiferal fauna and the molluscan assemblages (*Pachycrommium–Stigmaulax* assemblage and *Anadara willardaustena–Tellina–Strombina* assemblage of Saunders *et al.,* 1982) would agree with an environment of shallow-marine sand flats with patches of eelgrass interspersed with more active regions of sand waves.

The top of the Cercado Formation as seen in the river is marked by a coral-packed bed that is discordantly cut by the overlying conglomerate at the base of the Gurabo Formation. This bed may lens strongly or it may have been completely removed laterally as at NMB locality 15910 where the conglomerate rests directly on the underlying sands (Text-fig. 9; Pl. 1, fig. 1). The coral bed at some localities (*e.g.,* NMB loc. 16184; Pl. 1, fig. 3) shows colonies of (?) poritids almost in position of growth with breakage only due to compaction *in situ.* A coral thicket of poritids with some more massive heads and with common algal balls seems to have been the environment here.

Gurabo Formation.—The basal conglomerate has well-rounded but poorly-sorted polymictic components (Pl. 1, fig. 2). The igneous material is mainly melanocratic and may suggest a source not far away. This and the conformity of dip does not indicate any great deformational event at this level. There is no evidence for shallower water above the conglomerate; in fact, the influx of material does not seem to disturb the general trend of deepening. However, it must be remembered that as we go upsection we also go steadily further northward and, presumably, progressively further offshore as is illustrated in Text-figure 39.

The mollusc assemblages occurring in the lowest part of the Gurabo Formation (small *Anodontia–Turbo* assemblage and *Pachycrommium–Stigmaulax* assemblage) both point to a shallow-marine environment, whereas the assemblages characterizing higher parts of the Gurabo Formation indicate an increase in water depth.

The calcareous silts above the basal conglomerate become steadily richer upwards in microfauna with a more diverse foraminiferal assemblage rich in benthic species, and with planktic species beginning to appear. At first the latter are only represented by taxa, such as *Globigerinoides,* which are known to come further in-

shore than the keeled species of *Globorotalia,* though these begin to appear in small numbers towards the top of the interval. Ostracodes are common and more diverse but still dominated by shallow-water forms. Molluscs are abundant, as are solitary corals and calcareous algal masses. If a water depth of about 12 m is taken as the lower limit of rich *Thalassia* growth (Eva, 1980), such an environment is excluded from the section here and above.

Cross-bedded sands follow. They show strong bioturbation with large and small burrows filled with shells (Pl. 2, fig. 5). Though lithologically similar to the sands in the upper part of the Cercado Formation, these higher ones carry a deeper-water, more open-marine foraminiferal fauna. The instability of the bottom here, as in many other parts of the section, is borne out by the presence of solitary corals such as *Antillia, Antillophyllia,* and *Dominicotrochus.* By analogy with similar Recent genera, these seem to have been mobile forms, able to right themselves and even to migrate back to the surface if covered by sediment.

Outcrops of nearly 100 m of calcareous silts rich in both macrofauna and microfossils follow, and this interval, including stretches with poor outcrops, may total almost 200 m. Secondary calcareous cementation is common, forming harder layers and lines of flattened concretions; these probably reflect greater original porosity due to more coral debris at these levels (Text-fig. 10).The main feature of the interval is its richness in corals. Though some colonies could have been in position of growth, the great majority show evidence of movement on a slope. One of the best examples of this is at NMB locality 16933, where a chaotic mass of large coral heads has been tumbled, broken, and often inverted (Pl. 2, fig. 3). Corals include such reef-forming species as *Goniopora jacobiana* Vaughan, 1919 and *Montastrea* sp. Associated with the massive heads are branched corals (for example, branching poritids and a branching species of *Goniopora*) and these, though moved and fractured, are not completely disarticulated (Pl. 2, fig. 4). The evidence points towards mass movement of sediment downslope with coral colonies enclosed in sediment. Above and below the slump the bedding is more continuous but still suggests debris slides on a slope. The reason for such slides is uncertain but Stoddart (1972) has given convincing evidence for the effects of earthquakes on coral communities. The Cibao graben could well have been tectonically active at the time under review, making this mechanism important for some of the larger slides.

Depth of deposition is uncertain but very shallow-water corals that one would expect to find in reefs at less than 20 m water depth are conspicuously absent. The greater diversity of the benthic foraminiferal fauna and appearance of keeled planktic species suggests a depth probably greater than 40 m and open ocean circulation.

At 380 m on the column (Text-fig. 6) well-bedded alternating harder and softer layers are shown (NMB loc. 15837; Pl. 2, fig. 2). No biohermal coral masses occur but the beds could represent biostromal coral growth in patches, with development of major reef mounds prevented by scarcity of hard substrate and perhaps stress conditions due to high levels of fine sediment influx. Foraminiferal faunas again show access to the open ocean and a slowly increasing water depth. Ostracodes also show the first indication of deeper-water species at this level, while a general deepening of the water around this level is also suggested by the *Glycymeris–Polystira* mollusc assemblage.

A relatively rapid deepening takes place just below 400 m on the column (at the location of the bridge at Los Quemados; Pl. 2, fig. 1). Massive silts at first have coral debris beds and lenses of molluscan debris and packed shells of *Amphistegina* but they soon become more uniform. The ostracodes suggest a water depth greater than 200 m and the high ratio of planktic to benthic foraminifera also supports a depth of that order. Macrofossils are scarce in this environment.

Mao Formation. —The base of the formation is taken at a sudden influx of coarse terrigenous material, the basal conglomerate showing channeling, load features, flame structures and silt clasts. The badly-sorted material was swept into a relatively deep-water environment, probably by turbidity flows (Text-fig. 11; Pl. 3, figs. 4, 5).

Between 600 and 700 m on the column (Text-fig. 6) good outcrops show repeated influxes of pebbles, silt clasts and coral debris into the calcareous silt environment (Text-fig. 12; Pl. 3, fig. 3). Some of the coarser beds have erosional bases and load structures suggesting sudden turbidity inflow. Upslope from the site of deposition, conditions were intermittently unstable, perhaps due to shifting sources of supply of detritus, or perhaps reflecting increased wave action due to frequent storms.

At approximately 700 m on the column a tall cliff (Pl. 3, fig. 1) exposes alternating hard and soft beds. The latter are calcareous silts interspersed with calcarenites composed of coral debris, sand and pebbles that have become secondarily calcified. The silts may be somewhat shallower than below but still suggest a water depth greater than 100 m, into which the coarse debris has been swept. Discontinuous outcrops show this environment to continue at least as high as 770 m on the column.

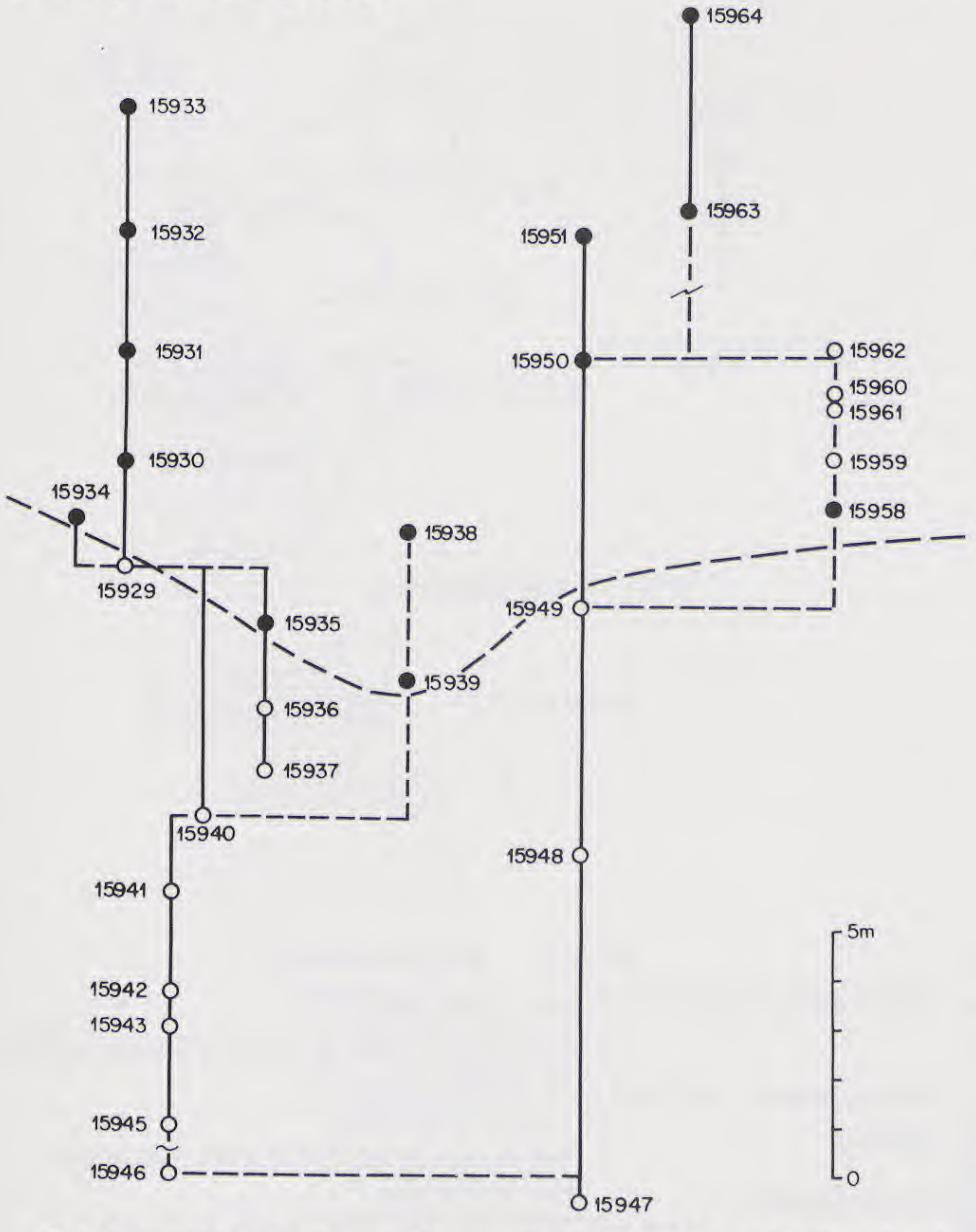
From about 650 to 750 m on the column a *Limopsis*–Pteropoda mollusc assemblage predominates. This as-

semblage also includes *Propeamussium*, terebratulid brachiopods, and small solitary corals, and thus points to considerable water depths.

Just above 800 m on the column "limestone" is found in minor outcrops on the valley slope and as blocks in the river. This lithology is a pebbly calcarenite with corals not in position of growth and an *Ostrea–Lithophaga* assemblage that also includes *Plicatula* and rare large echinoids.

The highest outcrops in the section, at around 900 m on the column, consist of channeled sands, grits and conglomerates (Text-fig. 13; Pl. 3, fig. 1). Distorted pebbly, clayey silt clasts are common. Plant fragments are particularly common in the sands along with scattered shell fragments. The silt clasts produce foraminiferal faunas that are environmentally heterogeneous but have a reasonable planktic component suggesting relatively deep water. The evidence points to turbitity and slump influxes into an environment of indeterminate water depth.

A large suite of samples has been studied for pollen and spores by Dr. E. Gonzalez, who has plotted frequency diagrams giving the quantitative distributions of major floral groups.



Text-figure 14.—Stratigraphic positions of NMB collecting localities (circles) across the Miocene–Pliocene boundary on the Río Gurabo (see Text-fig. 4, lower middle). The boundary is indicated by the dashed line. The vertical lines represent single outcrops. Black circles indicate the presence of *Globorotalia margaritae*.

Throughout the section the flora is dominated by pteridophytes (mainly ferns). There is a gradual up-section increase of angiosperms, mostly represented by savanna and coastal plain elements, with palms being important. There is also an increase of gymnosperms (particularly the conifer *Podocarpus*) and of temperate angiosperms towards the top of the section. No forest development is seen. Mangrove pollen occurs in only a few samples and then only as a few grains.

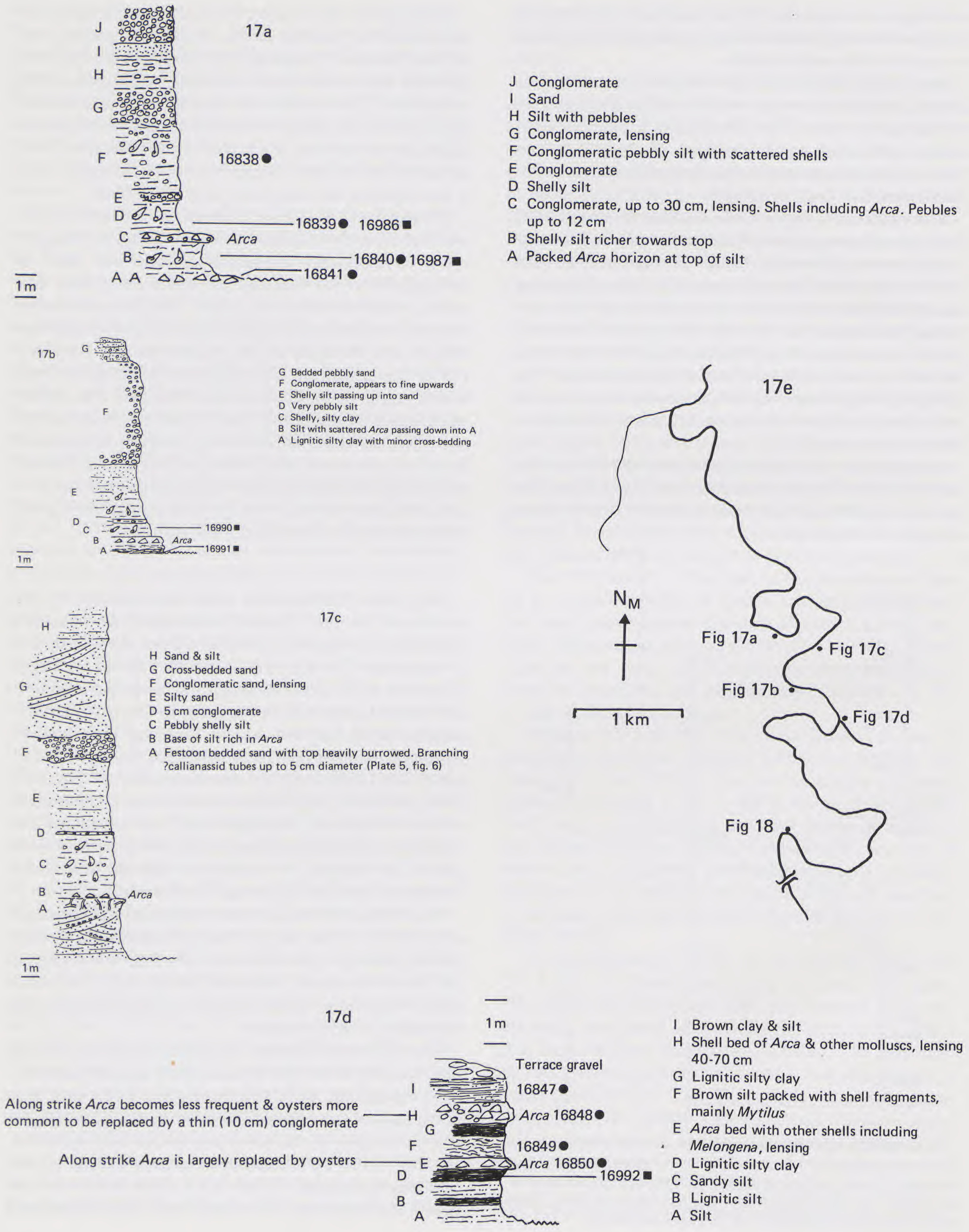
Abrupt floral changes are absent except between 300 and 400 m on the column where the change to a deeper-water environment apparently affected the input of fine, land-derived material of which the pollen and spores would have formed a part. The gradual upward increase of plants requiring a cooler climate is perhaps mainly due to uplift of the hinterland but may also reflect the beginning of a regional temperature drop, which could be expected in the Pliocene. The earlier appearance of temperate forms such as *Alnus* (alder) and *Quercus* (oak) in this area, relative to northern South America and some other parts of the Caribbean, may reflect the considerable topographic expression of the Cordillera Central, which still today has the highest elevation in the Caribbean (3087 m).

Age

The larger foraminifera from thin sections of the limestones in the Tabera Formation (the Monción Limestone of Palmer, 1979) have been studied by Dr. J. Butterlin. The majority of samples fall in the range P18 Zone to N5 Zone (that is, *Cassigerinella chipolensis/Pseudohastigerina micra* Zone to *Catapsydrax dissimilis* Zone); they are thus in the range from middle Oligocene to early part early Miocene. The age of sample NMB 16220 is given more precisely by Dr. Butterlin as P19 or P20, which would make it equivalent to the *Globigerina ampliapertura* Zone of the middle Oligocene. As considerable section seems to be present above this sample, it is possible that the top of the limestone could be as young as Miocene.

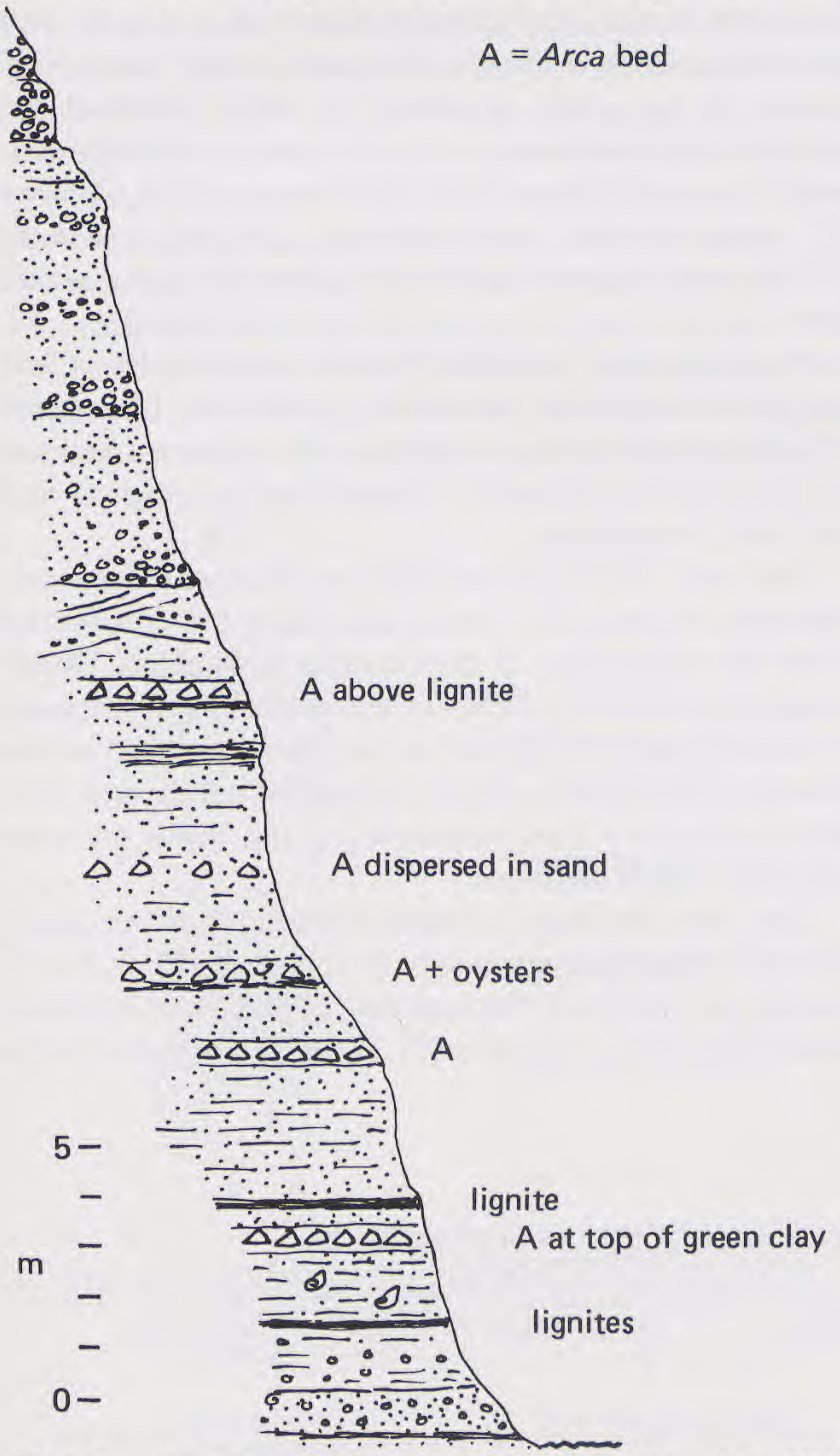
The bottom of the Cercado Formation has been dated as NN11 Zone on the basis of calcareous nannofossils, making it late Miocene. The first occurrence of the ostracode genus *Radimella* at the top of the Cercado Formation would support a late Miocene age throughout this formation.

The Miocene–Pliocene boundary is placed on the first occurrence of the foraminiferal species *Globorotalia margaritae* Bolli and Bermudez, 1965, and thus is the base of the zone of the same name. The detailed plot of samples at this level is given in Text-figure 14. As the NN11–NN12 zonal boundary occurs at approximately sample NMB 15941 only about five m below the incoming of *G. margaritae*, this nannofossil


17a
J
I
H
G
F
E
D
C
B
A A
16838
16839 16986
Arca
16840 16987
16841
1m
J Conglomerate
I Sand
H Silt with pebbles
G Conglomerate, lensing
F Conglomeratic pebbly silt with scattered shells
E Conglomerate
D Shelly silt
C Conglomerate, up to 30 cm, lensing. Shells including Arca. Pebbles up to 12 cm
B Shelly silt richer towards top
A Packed Arca horizon at top of silt
17b
G
F
E
D
C
B
A
16990
Arca
16991
1m
G Bedded pebbly sand
F Conglomerate, appears to fine upwards
E Shelly silt passing up into sand
D Very pebbly silt
C Shelly, silty clay
B Silt with scattered Arca passing down into A
A Lignitic silty clay with minor cross-bedding
17c
H
G
F
E
D
C
B
A
Arca
1m
H Sand & silt
G Cross-bedded sand
F Conglomeratic sand, lensing
E Silty sand
D 5 cm conglomerate
C Pebbly shelly silt
B Base of silt rich in Arca
A Festoon bedded sand with top heavily burrowed. Branching ?callianassid tubes up to 5 cm diameter (Plate 5, fig. 6)
17e
N_M
1 km
Fig 17a
Fig 17c
Fig 17b
Fig 17d
Fig 18
17d
1m
Terrace gravel
I
16847
Along strike Arca becomes less frequent & oysters more common to be replaced by a thin (10 cm) conglomerate
H
Arca 16848
G
F
16849
Along strike Arca is largely replaced by oysters
E
Arca 16850
D
16992
C
B
A
I Brown clay & silt
H Shell bed of Arca & other molluscs, lensing 40-70 cm
G Lignitic silty clay
F Brown silt packed with shell fragments, mainly Mytilus
E Arca bed with other shells including Melongena, lensing
D Lignitic silty clay
C Sandy silt
B Lignitic silt
A Silt

Text-figure 17.—Sections in four cliff exposures (Text-figs. 17a–d) of the Cercado Formation on Río Cana, showing the relationship of the *Arca patricia* beds to the surrounding sediment types. Geographic locations of exposures are shown in Text-figure 17e (see Text-fig. 15 for more detail). Black squares represent localities collected for microfossils and lithologic analyses; black circles represent localities collected for macrofossils. For more details on Text-figure 17a, see Plate 4, figure 3; for more details of Text-figure 17c, see Plate 5, figure 6; for more details on Text-figure 17d, see Plate 4, figure 4.

datum level is also taken to represent the epoch boundary. Comparative zonal charts usually show the NN12 Zone extending down slightly into the Miocene (Table 4) but in the Gurabo section the two horizons are seen to be very close indeed. The plot of the position of the micropaleontological samples (Text-figs. 4, 14) shows that due to the very low dip and the large meanders in the river, the boundary is crossed several times, and this adds credence to its mapping. The water was deepening rapidly at about this time but because of the presence of considerable numbers of menardiform Globorotalias already in samples below the boundary, it is not thought that the first occurrence of *G. margaritae* is facies controlled. Also, the swing in coiling direction of the menardiform Globorotalias from predominantly sinistral, through random, to almost entirely dextral at the boundary strongly supports its placement. Vail, Mitchum, and Thompson (1977) have proposed a series of global eustatic sea level changes through time based on seismic stratigraphy. At the Miocene–Pliocene boundary an abrupt relative rise of sea level amounting to about 140 m is illustrated by them. In relation to the increase in water depth near the boundary as suggested in the Río Gurabo section this fits very nicely, though one cannot see a sea level change of comparative magnitude in the Rio Cana section only 10 km to the west.



Text-figure 18.—Section exposed in cliff near NMB locality 17000 in the Cercado Formation on Río Cana, showing the position of the *Arca* beds ("A"). The geographic position of this section is shown in Text-figure 17e (see Text-fig. 15 for more detail). See also Plate 4, figure 1.

From 400 to 700 m on the column (Text-fig. 6) planktic foraminiferal faunas are usually good and a determination of *Globorotalia margaritae* Zone, Pliocene is possible, though the two subzones that are known in richer assemblages are not used here (see explanation of Table 4). The foraminiferal findings agree with the nannofossil dating of zones NN12 to NN15.

The upper part of the column above about 710 m is dated as *Globorotalia miocenica* Zone, middle Pliocene. The base of the zone is above the fault shown on the column (Text-fig. 6) and the structural break may not have any great significance. Sample NMB 16094 above the fault is still within the *G. margaritae* Zone. Division of the *G. miocenica* Zone into its two subzones (see explanation of Table 4) has not been attempted due to the poor and scattered faunas in the uppermost outcrops. However, the section is still in the lower subzone (*Globigerinoides trilobus fistulosus* Subzone) at least as high as 770 m, based on the presence of *Globoquadrina altispira* sensu lato in sample NMB 16108. The highest outcrop contains a sample dated as high NN15 Zone, based on nannofossils. This does not entirely agree with the correlation between nannofossils and foraminifera given in Table 4, as it would suggest that the section is still high in the *G. margaritae* Zone, whereas on foraminifera it is probably already within, and perhaps towards the top of, the *Globorotalia exilis* Subzone.

Río Cana

General

The central part of the Río Cana section was tackled by using a track leading from the road south of the village of Zamba. Long stretches can only be reached

on foot and the limestone gorge is difficult of access and impassable at above average water levels. Access to the gorge from the north requires a long walk from Cana Chapetón on the road connecting Guayubín and Mao.

The upper reaches of the Cana are equally difficult to reach with a vehicle but it is possible to drive to Cementerio (Dominican Republic Grid ref. BM508633) which is close to the contact between the Cercado Formation and the underlying rocks of the Cordillera Central.

In the Río Cana and Cañada de Zamba approximately 75 samples were taken for microfossils and lithologic study and 71 for macrofossils over a period of 11 days.

Lithology

In the Río Gurabo, the lithologic sequence was discussed under the headings of the formation names that have been used in the past. This is possible in that river section because the Gurabo Formation in its type area separates the underlying Cercado Formation from the overlying Mao Formation. However, when one goes 10 km to the west to a parallel section exposed in the Río Cana, it is apparent that lateral changes make it impossible to correlate lithologic units except in a broad way. On the column (Text-fig. 16), a tentative subdivision into formations has been included and this breakdown is defined in Appendix 1, but no great emphasis is placed on the formational subdivision in this part of the text.

The section begins with 75 to 100 m of conglomerates and cross-bedded sands that follow unconformably immediately above steeply-dipping, hard shales and sandstones of the Cordillera Central.

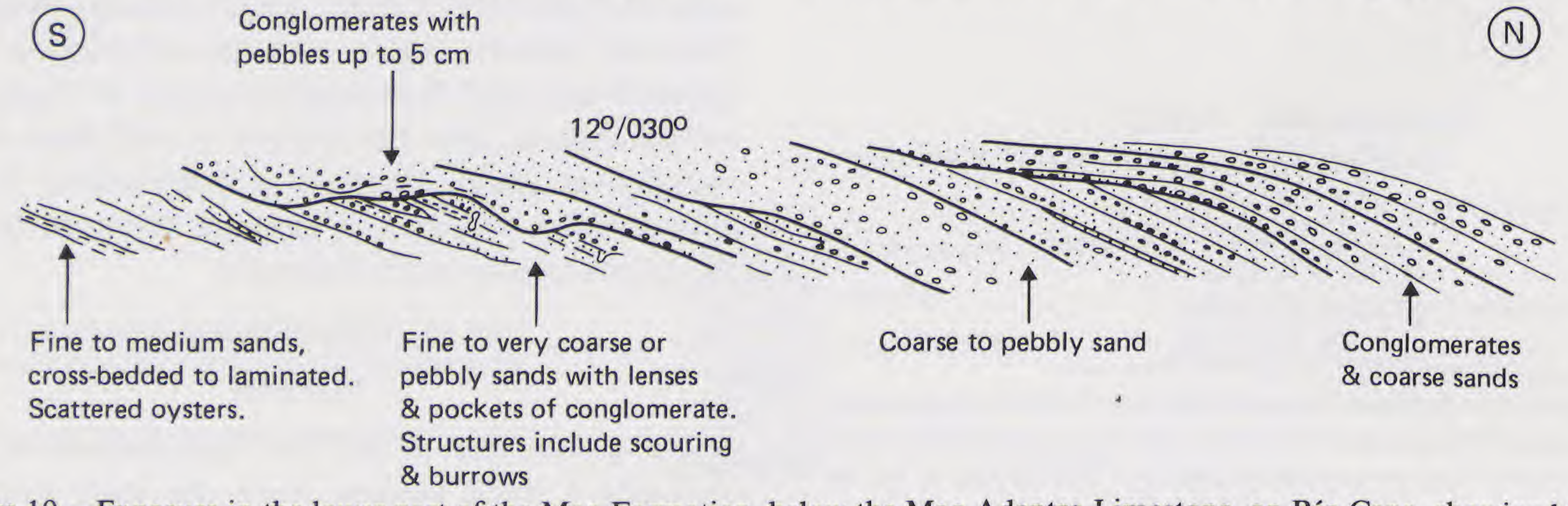
Above an unexposed interval follow channeled and cross-bedded sands, often pebbly and with interbedded conglomerates. Silts and lignitic silts are also frequently associated with minor lenses that are rich in molluscan debris and, occasionally, coral debris.

Higher in the section, sands and sandy silts predominate with conglomerates and occasional shell beds. Particularly distinctive are a number of levels rich in large specimens of the bivalve *Arca patricia* G. B. Sowerby, II, 1850, which also dominate the river float downstream. Details of these occurrences are given in Text-figures 17 and 18 and in the Explanation of Plate 4. In a single cliff face (Pl. 4, fig. 1), five *Arca* levels can be traced, and downstream some or all of these can be seen at river level. Correlating a particular shell level from one outcrop to another is not easy as single localities show how discontinuous the *Arca* beds can be and how they may change laterally within a few meters into oyster beds or into conglomerate lenses. Text-figures 17a to 17d exhibit details of the types of sediment in which the *Arca* beds occur. Two of the beds (see Text-fig. 17d; Pl. 4, fig. 4) occur in rhythmic series where they are preceded by a highly lignitic bed and followed by a clayey silt packed with shell fragments (in one case, *Mytilus*). In other localities the *Arca* horizons are associated with sands and shelly silts, sometimes with large-sized *Callianassa*-type burrows (Pl. 5, fig. 6). The *Arca* beds were grouped by Maury (1931) in her Caimito Formation but this unit has not been found to have any lateral correlative value.

The base of the Gurabo Formation in the Río Cana has been tentatively placed at the bottom of a series of pebbly sands and a conglomerate with components up to 10 cm in diameter. Channeling is common and the base is erosional.

The next 300 m of section are dominated by calcareous silts and silty sands and these are considered to be the equivalent of the Gurabo Formation. Minor conglomerates and pebbly layers occur sparsely except in what is still considered to be the upper part of the Gurabo Formation, where channeled sands and conglomerates with load structures at the bases are considerably more frequent.

The basic lithology is highly calcareous silt or sandy silt with abundant secondary concretions (Pl. 5, fig. 4). Corals are common throughout in the form of heads and of branching colonies (Pl. 5, fig. 3). At some levels,



Text-figure 19.—Exposure in the lower part of the Mao Formation, below the Mao Adentro Limestone, on Río Cana, showing high-angled foreset beds in coarse sands and conglomerates. This sequence appears at 630 m above the base of the section on Río Cana (see Text-fig. 16).

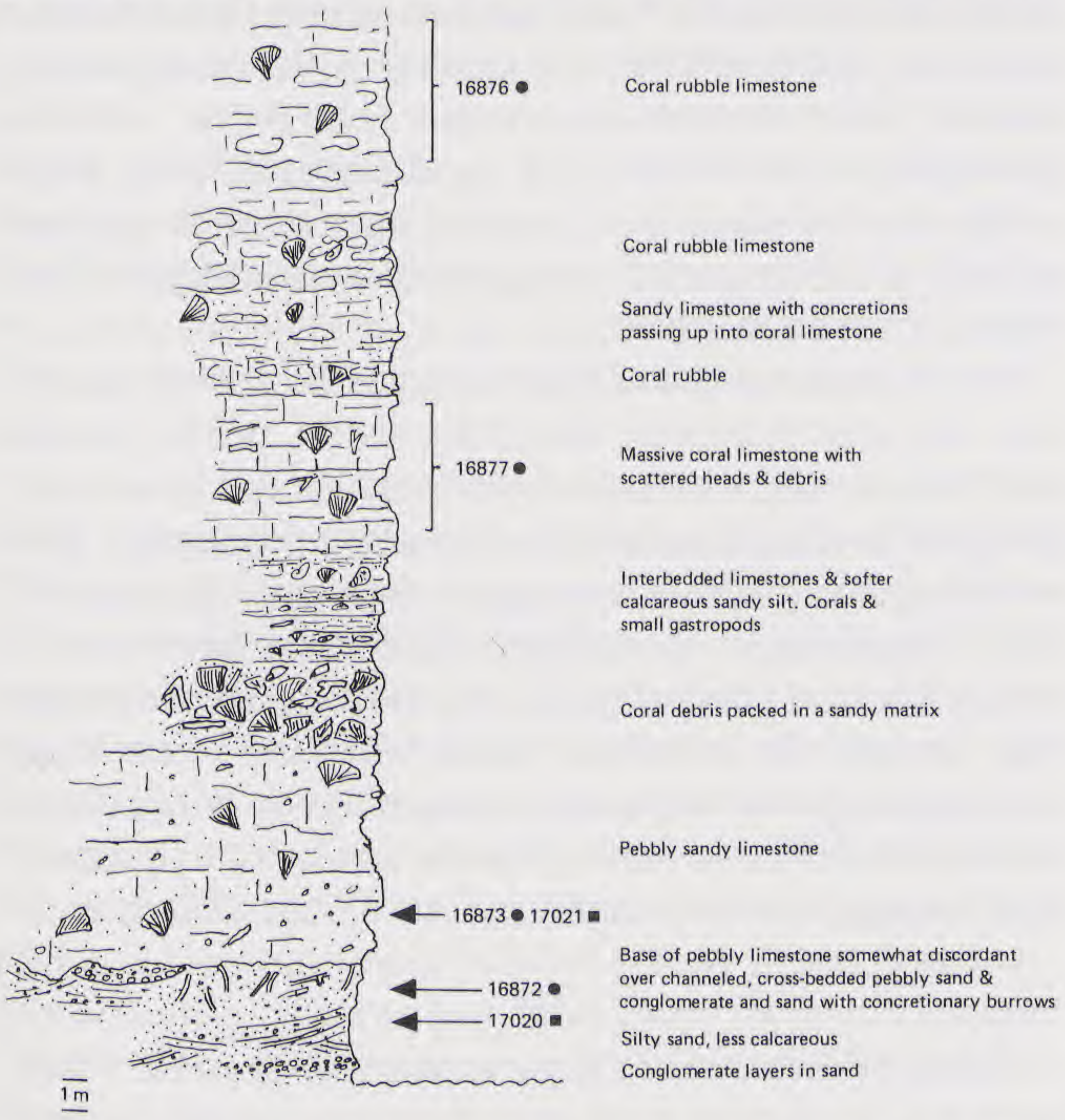
particularly in the Cañada de Zamba, they indicate true reef structures. In many other places they are in the form of debris that could often indicate reef talus. Molluscs are frequent either scattered through the silts or as shell horizons. Particularly in the lower part of the interval, spherical shells of the foraminifer *Sphaerogypsina* are thickly distributed and easily visible. Burrowing is common at many horizons.

The base of the Mao Formation has been drawn where calcareous silts are replaced by conglomerates, pebbly grits and sands. A spectacular outcrop of conglomerates and coarse grits prograding towards the northeast (Text-fig. 19; Pl. 5, fig. 1) is followed by a poorly exposed interval, probably mainly of sands.

Unlike the situation in the Río Gurabo section, limestones are well developed in the Río Cana within the Mao Formation ("Mao Adentro Limestone"). The river has cut a deep, narrow gorge through an estimated thickness of 340 m of limestone (Pl. 6, fig. 3).

Below the limestone are cross-bedded, heavily burrowed, pebbly sands and thin conglomerates. These pass abruptly into pebbly, sandy limestone that appears to be somewhat discordant locally (Text-fig. 20; Pl. 6, fig. 2).

The major part of the limestone is massive. Coral heads and branching colonies are visible but not tightly packed except as debris beds in a calcarenitic matrix.



Text-figure 20.—Section through the base of the Mao Adentro Limestone on Río Cana. See Text-figure 15 for geographic and stratigraphic positions of localities. See also Plate 6, figure 2. Black squares represent NMB localities collected for microfossils and lithologic analyses; black circles represent NMB localities collected for macrofossils.

At the top, the bedding is much more pronounced, with thin calcareous siltstones alternating with coral-rich, flaggy limestones (Pl. 6, fig. 1).

A long, covered interval occurs downstream from the limestone gorge and, as the country is relatively flat, this probably represents the clays that follow the limestones in the Mao Formation in the type section.

As in the Río Gurabo, the highest beds seen are sands with minor conglomerates. The bedding here is more uniform than in the Río Gurabo while shells and coral debris are commoner, together with frequent plant debris.

Environment

Unfossiliferous, poorly-sorted conglomerates rest on steeply-dipping shales and sandstones. The base of the series here could be fluviatile with material dumped under rapidly-fluctuating energy conditions. A superjacent covered interval is in turn overlain by channeled sands and carbonaceous clays. Shell debris shows the environment to have been shallow marine and the character of the beds suggests basically low energy conditions with frequent floods of coarser material. Upwards, cross-bedded, pebbly sands and conglomerates suggest similar conditions but with a slightly increased marine microfauna found in lenses and comprising molluscs, coral fragments and echinoid debris.

The interval including the *Arca patricia* and oyster beds, characterized by the *Larkinia–Mytilus–Melongena* mollusc assemblage of Saunders *et al.* (1982), reflects brackish water conditions. *A. patricia* is closely related to the Recent Eastern Pacific species *A. grandis* (Broderip and Sowerby, 1829). Woodring (1973, p. 512) even considered it as a subspecies of the living form, citing it as *Anadara* (*Grandiarca*) *grandis patricia*. According to Maury (1922, p. 194), *A. grandis* lives in mud between tides, and it is restricted to a mangrove swamp habitat (Olsson, 1932, p. 62). Olsson (1961, p. 94) stated that "its usual habitat is lying deeply buried in soft mud banks which border mangrove swamps; hence, its distribution coincides with that of the mangrove". If *A. patricia* had a habitat similar to that of *A. grandis,* pollen samples from that interval should yield abundant mangrove pollen. Unfortunately the relevant samples of the Río Cana section have not yet been studied, but palynological examination of Río Gurabo samples has shown mangrove pollen to be almost absent (see p. 17).

The *A. patricia* beds not only contain *A. patricia* but are characterized by an oligotypic fauna consisting of varying combinations of species of the genera *Bulla, Melongena, Anadara, Mytilus,* few large oysters, and *Corbula.* Even where *A. patricia* is replaced to a great extent by large oysters (see Text-fig. 17d), the oligotypic

assemblage still exists but now contains only small numbers of *A. patricia, Mytilus,* and *Corbula.*

A minimum of five discrete *Arca* horizons span a thickness of section of at least 10 m (Text-fig. 18). The sketch sections in Text-figure 17 show that these occur in different lithologic sequences at various localities. The most brackish would be the two beds both preceded by highly carbonaceous clays and separated by a silt packed with *Mytilus* (Text-fig. 17d; Pl. 4, fig. 4).The most northerly occurrences of *Arca* beds, on the other hand, are associated with sands rich in *Callianassa*-sized burrows and with shelly silts rich in shallow marine molluscs, bryozoans and *Amphistegina* (Text-figs. 17a, b, c; Pl. 4, figs. 2, 3; Pl. 5, fig. 6).

The environment continues to be shallow-marine upwards with an influx of sands and pebble beds suggesting relatively high energy until a minor unconformity is seen at the base of a polymictic conglomerate rich in well-rounded, melanocratic pebbles. Burrowing is common but the macrofauna is not rich. Some of the finer-grained layers are rich in *Amphistegina, Cuneolina* and small molluscs. The shells of *Amphistegina* in particular may show considerable wear.

The conglomerate cited above is taken as the base of the Gurabo Formation in the Río Cana. Ostracode results give the best clues to correlation and these are considered in the section dealing with age.

Above the conglomerate there is a change in style of sedimentation with a long sequence of calcareous silts with frequent horizons rich in corals. Compared with the Río Gurabo section, potentially frame-building corals are much better represented, though only at one locality (NMB loc. 16813) at the mouth of the Cañada de Zamba is there an association of platy reef corals with common *Agaricia,* comparable to that found on the outer slopes of present-day Caribbean reefs below 20 or 30 m water depth. Water depths were probably less than 30 m. Shallow benthic foraminiferal faunas are, as usual, rich in *Amphistegina* but also are peppered with large, spherical *Sphaerogypsina* easily visible to the eye (Pl. 5, fig. 5). These, together with *Planorbulina* and frequent miliolids, attest to the shallow-marine, clear-water environment and suggest relatively low energy levels. The very low percentages of planktic species could reflect restricted oceanic circulation but are probably merely a result of the shallowness of the water. Molluscs are frequent throughout and discrete shell beds occur as, for example, one rich in the large bivalve *Anodontia,* which usually has both valves still present. Lines of secondary concretions are a feature of the silts showing that the original sediment was extremely calcareous (Pl. 5, fig. 4).

Within the upper part of the calcareous silts, at around 500 m on the column (Text-fig. 16), an influx of coarser material in the form of cross-bedded sands and pebble beds requires higher energy, erosional bottom currents (Pl. 5, fig. 2).

Further influxes of terrigenous material, including spectacular foresets in conglomerates and grits (Text-fig. 19; Pl. 5, fig. 1), are taken to represent the lower part of the Mao Formation. There is probably a shallowing at this level as suggested perhaps by these sedimentary features and, more particularly, by the *Ostrea–Lithophaga* molluscan assemblage (Saunders *et al.,* 1982).

Shallow, inshore conditions persisted to the base of the limestones that are taken to represent the Mao Adentro Member. Pebbly, sandy limestone begins to build on an uneven surface of cross-bedded, heavily burrowed sands that contain a very shallow-water foraminiferal fauna (Text-fig. 20; Pl. 6, fig. 2).

The paleoenvironment represented by the 340 m of limestone as exposed in the river gorge is not yet fully understood. At the top (Pl. 6, fig. 1) and bottom (Pl. 6, fig. 3), bedding is well marked but the rock is more massive towards the center. Where examined, it is seen to contain abundant massive and branching corals but many of these are fragmented and not in growth position. Also, the colonies are not sufficiently densely packed to form a true reef framework. Repeated surges of coral debris downslope seem to be the most logical explanation of cause based on our present knowledge. A sample taken in softer clays between the coral rubble beds in the youngest limestones (NMB loc. 17023) produced a surprisingly rich foraminiferal fauna with a high ratio of planktic to benthic species and was rich in keeled Globorotalias, suggesting a water depth of at least 100 m at this point.

The topmost series of beds exposed in the river section includes relatively flat-lying sands, pebbly sands and minor conglomerates that contain coral debris and scattered molluscs and are rich in plant fragments. The environment is difficult to judge because it is possible that everything is introduced. However, the foraminiferal fauna is relatively rich, considering the lithology and, though the benthics could represent more than one environment, there is a strong planktic component somewhat different from that known below. It would again suggest a water depth of more than 100 m.

Age

The shallower water environment of the Río Cana section as compared with that of the Río Gurabo makes dating by planktic microfossils less certain.

The bottom of the section has so far proved to be undatable based on planktic foraminifera and calcareous nannofossils. Planktics begin to appear around 300 m on the column and, on a poor sample giving a

Table 2.—Ostracode datum points for the Río Gurabo and Río Cana sections (see Text-figs. 4 and 15, respectively), supplied by Dr. W. A. van den Bold.

<table>
<tr><th rowspan="2">Ostracode datum point</th><th colspan="2">Rio Gurabo</th><th colspan="2">Rio Cana</th></tr>
<tr><th>NMB sample number</th><th>Height in column (m)</th><th>NMB sample number</th><th>Height in column (m)</th></tr>
<tr><td>Base Munseyella sp. 2</td><td>15982</td><td rowspan="2">527</td><td>17010</td><td>430</td></tr>
<tr><td>Top Munseyella sp. 1</td><td>15982</td><td>16964</td><td rowspan="2">384</td></tr>
<tr><td>Top Coquimba congestocostata</td><td>15933</td><td>410</td><td>16964</td></tr>
<tr><td>Top Radimella sp. 1</td><td>15958</td><td>398</td><td>17006</td><td>352</td></tr>
<tr><td>Base Gangamocerithidea ? plicata + Cytherella A</td><td>16178</td><td>160</td><td>16978</td><td>282</td></tr>
<tr><td>Base Radimella genus</td><td>16186</td><td>146</td><td>17004</td><td>165</td></tr>
</table>

predominance of dextrally- over sinistrally-coiled menardiform Globorotalias, the base of the Pliocene is thought to be at least as low as about 315 m. This seems to agree with a determination of ?NN12 Zone based on nannofossils at 345 m (in the Cañada de Zamba). If the situation here is as in the Río Gurabo, the NN12 Zone can be expected to be quite thin, which would fit the placing of the base of the Pliocene around 300 m, with a change to NN13–NN14 Zone by 370 m.

Between this level of the column and the top of the Mao Adentro Limestone, faunas are poor though a Pliocene age is always suggested by the coiling ratios of menardiform Globorotalias. A surprisingly rich planktic component of the foraminiferal fauna in sample NMB 17023, about 40 m below the top of the limestone, is considered to represent the topmost *Globorotalia margaritae* Zone or the basal *Globorotalia miocenica* Zone. When Text-figure 16 was printed, we had a determination of NN16–NN18 Zone, based on nannofossils, but this has since been revised to upper NN15 Zone, giving better agreement between the two fossil groups.

Considering the coarse lithology of the highest outcrops, the planktic fauna is better than might be expected. It gives an age still within the middle Pliocene and not above the middle of the *Globorotalia exilis* Subzone of the *Globorotalia miocenica* Zone.

Some interesting tie-points between the Río Gurabo and Río Cana sections are suggested using ostracode datum levels supplied by Dr. W. A. van den Bold. Information from him has been used to construct Table 2.

The first occurrence of the genus *Radimella* seems proven as being below the base of the Pliocene on the evidence of the Río Gurabo section. Its equivalent position in the Río Cana section, where the location of the base of the Pliocene is much less certain, is an important factor.

Río Yaque del Norte

General

The part of the river included in the present study stretches from Baitoa in the south, past the confluence with the Río Bao, and northwards for 13 km to the city of Santiago (Text-fig. 22). This represents a distance of 20 km along the river and therefore time only permitted visits to some of the major outcrops along this length. The intention was to try to make a general comparison between this section and those seen to the west with the hope of recognizing lateral facies changes. A reconnaissance survey was carried out to the south of Baitoa by geologists of the Institut Français du Pétrole, who mapped a thickness of more than 1000 m of conglomerates, shales and silts below our section. These

beds have been grouped as the Represa Conglomerate Formation of the Tabera Group by Palmer (1979).

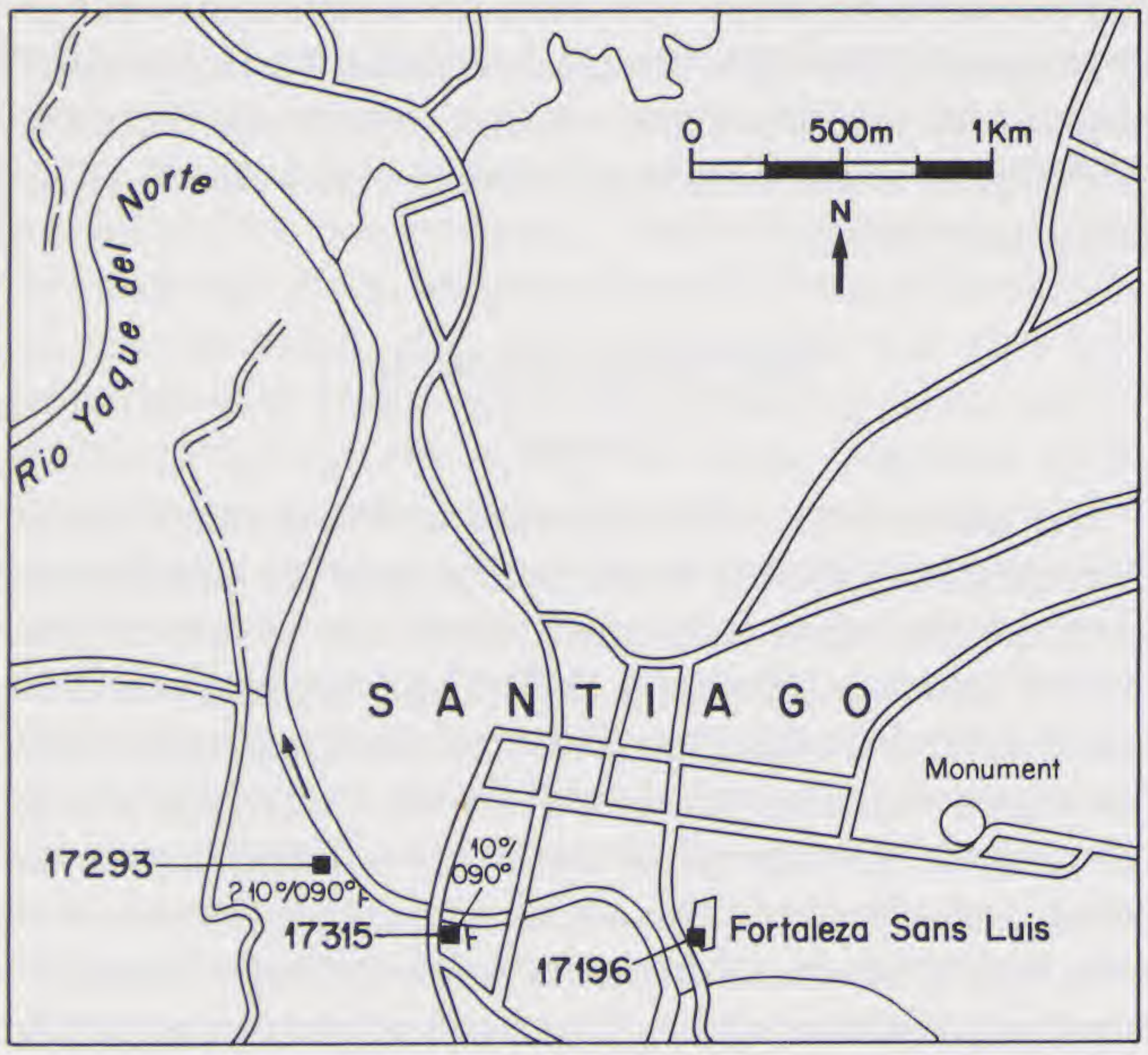
A few spot samples were also taken along the old road from Santiago to Baitoa and on the Río Bao: these are plotted on Text-figure 23. Fifty-eight samples were taken in the area for microfossils and lithologic study and 36 for macrofossils.

Lithology

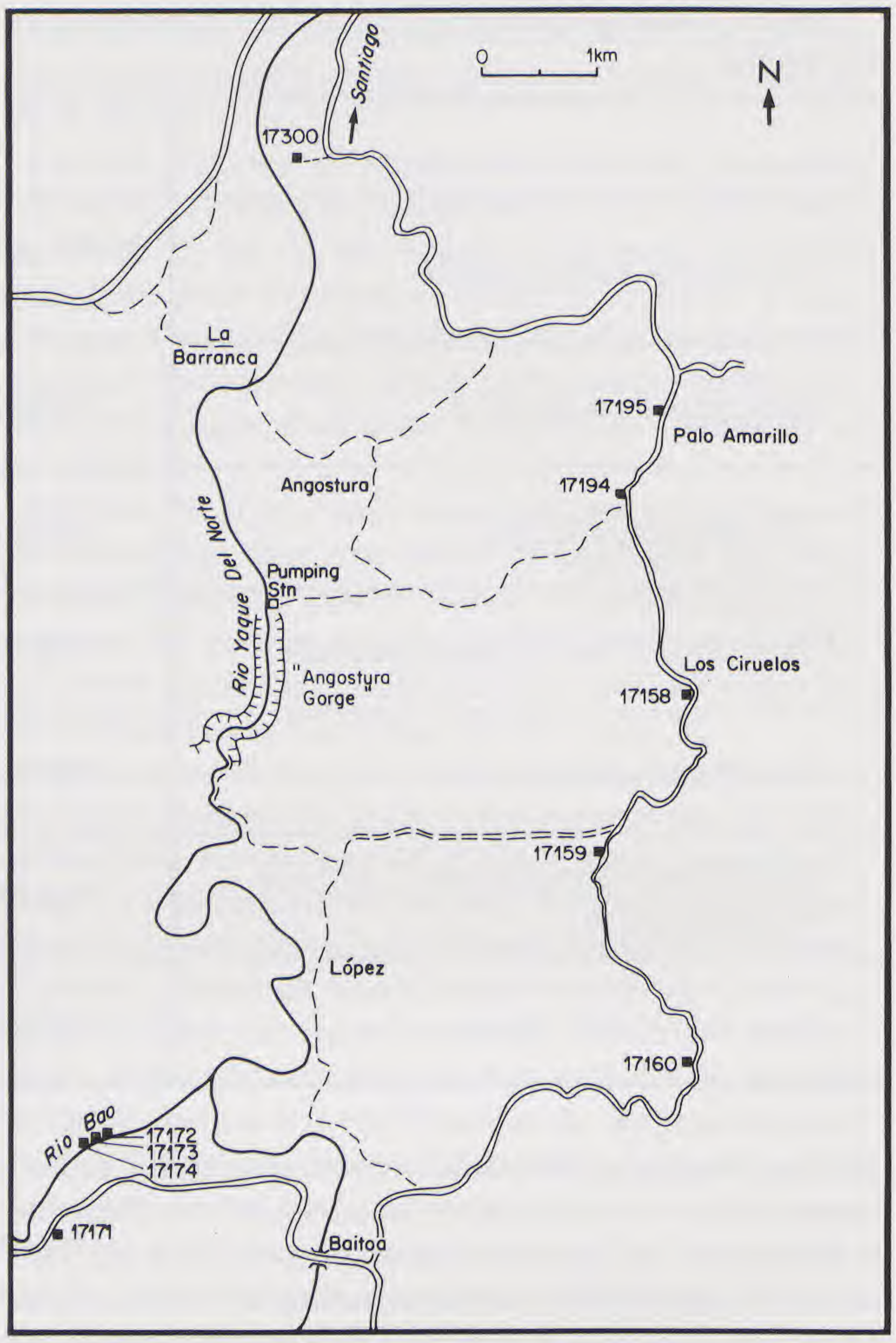
Beds below the Miocene unconformity at López (Text-figs. 24, 25).—The section including the unconformity was particularly well exposed in the river in 1980, as the extra water flow resulting from a hurricane that year had cleaned away much of the vegetation that had masked the bottom of the cliffs on earlier visits. A very clear angular discordance makes the unconformity easily visible. The dip is 10° above and 20° below with a change of approximately 10° in strike direction. Twenty m of section was closely examined below the unconformity (Text-fig. 25). It consists of conglomerates to coarse, pebbly sands, all poorly sorted and sometimes indistinctly graded. Components are well rounded and consist of dark igenous rocks, dark limestones and hard siltstone clasts that have been used for dating. Broken molluscs and coral heads occur sparsely throughout and more commonly at a few horizons. Up the river the section was seen to continue downwards in a predominantly conglomeratic facies.

The river cliffs just north of Baitoa expose somewhat lower beds that are also truncated by the unconformity (see photograph in Text-fig. 28). Calcareous silts are separated by occasional thin, sandy conglomerates. These would fall in the Janico Formation of Palmer (1979). Upriver from the new bridge at Baitoa, conglomerates become more dominant again and interbedded conglomerates and pebbly sands with occasional thin shales are at least 1000 m thick. These comprise the Represa Formation of Palmer (1979). Both Janico and Represa formations are part of the Tabera Group. It is possible that Palmer did not see the river section used for the construction of our Text-figure 25 as he makes no mention of the strongly conglomeratic facies below the unconformity at that point.

Beds above the Miocene unconformity at López (Text-fig. 25; Pl. 9, figs. 1, 2).—Fifty-five m of beds were examined closely and sampled extensively. Pebbly, well-bedded, fossiliferous silts predominate with many

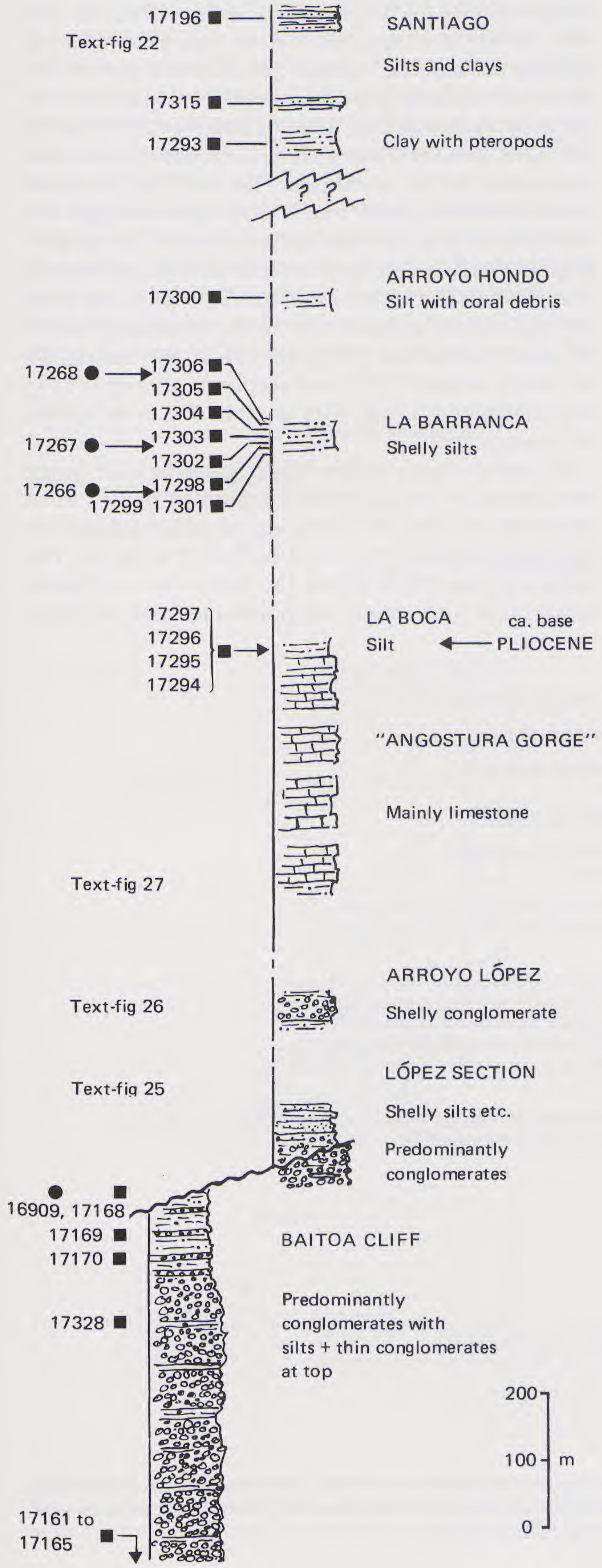


Text-figure 22.—Map of the city of Santiago (area 7 on Text-fig. 3), showing geographic positions of NMB microfossil collecting localities (black squares).



Text-figure 23.—Map showing geographic positions of NMB microfossil collecting localities (black squares) along the road between Santiago and Baitoa and on Río Bao.

Text-figure 24.—Schematic column for Río Yaque del Norte, showing relative stratigraphic positions of localities and estimated thickness of strata. Black squares represent NMB localities collected for microfossils and lithologic analyses; black circles represent NMB localities collected for macrofossils. The coverage of other Text-figures herein is shown.



conglomeratic and coarse sandy layers. Where the beds can be followed along strike for some meters, the lensiform nature of individual layers is very evident. This was made apparent by comparing exposures before and after the hurricane of 1980 during which there was active lateral erosion. Sorting in the coarser grades is poor; the clay and fine-silt fractions have been winnowed out. Secondary calcification is common, forming bands of irregularly oval concretions in the direction of bedding; hard calcarenite beds are the final stage at some levels. Shell-filled burrows and lenses of shells and shell debris are common (Pl. 8, figs. 3,4). Plant fragments, up to more than one m in long dimension, occur at many horizons. Lensing conglomerates contain boulders up to 35 cm in diameter and coral heads up to 50 cm. Some corals were growing attached to boulders. Components in the conglomerates are generally well rounded and mostly of igneous origin with, overall, melanocratic types exceeding leucocratic. The Cretaceous Duarte Formation now exposed in the Cordillera Central to the south of the Baitoa area may have provided much of the more basic material while the lighter-colored intrusive tonalites could have given rise to the leucocratic pebbles. Tabera conglomerates were exposed on the unconformity before deposition of the beds above, making it likely that much material is at least second generation.

The name Baitoa Formation was defined by W. Cooke (*in* Vaughan *et al.,* 1921) as comprising the beds at the top of the cliffs downstream from Baitoa ('Baitoa Cliff' of Text-fig. 28). This location was made the type locality but it was stated that collecting from the cliffs is not easy and that the old trail from Baitoa to Santiago provides better accessibility. Vokes (1979) gave a good photograph of these cliffs but also did most of her collecting on the track where weathering has led to poorer preservation of the fossils. Only Ramírez (1956) mentions a locality in cliffs below the confluence of the Río Bao with the Río Yaque and this must surely be our López section (see Text-figs. 21, 23).

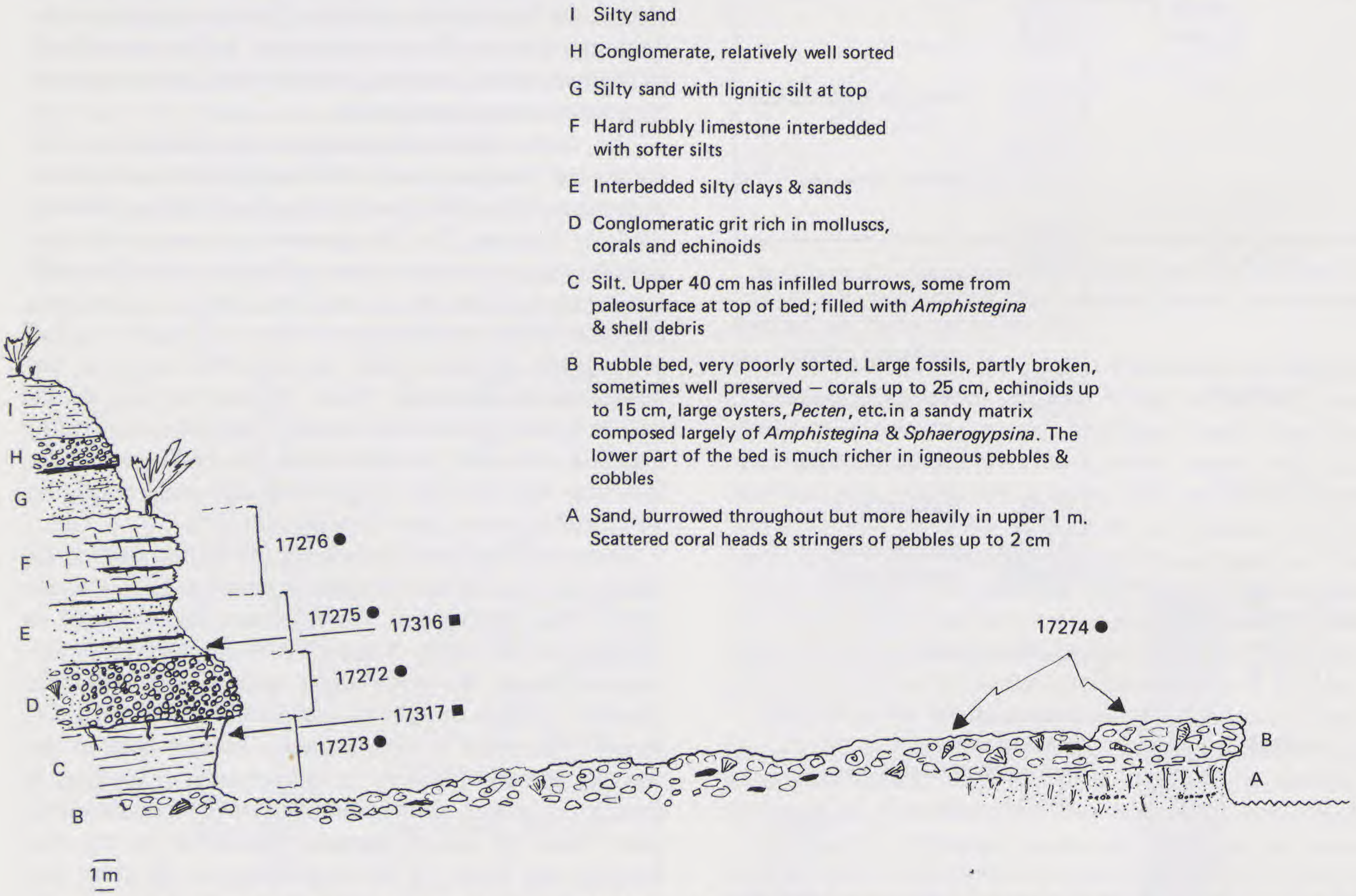
Some authors have considered the Baitoa beds to be within the base of the Cercado Formation (*e.g.,* Cooke, 1920, 1921; Bermudez, 1949) while others (Cooke *in* Vaughan *et al.,* 1921; Vokes, 1979) have given it formational rank. We would agree with the latter for two reasons: 1) both lithofacies and biofacies are very different from what is seen in basal Cercado beds to the west, as the environment is fully marine at Baitoa; 2) present evidence shows the beds to be considerably older than the basal Cercado Formation in the Río Gurabo (see Table 4). We here designate the river section south of López where the Arroyo Hondo joins the main river (Text-figs. 21, 25; Pl. 8) as a hypostratotype because of the quality of the outcrop (see Hedberg, 1976, pp. 26, 38). This locality is approximately 400

m north of the original type locality cliff. Formal definitions are given in Appendix 1.

In contrast to the use of the term "Baitoa Formation", the basal beds above the unconformity along the river have been placed in the Bulla Conglomeratic Member at the base of the Cercado Formation by Palmer (1979, folded map). In road and river sections to the west, particularly at Bulla on the Río Mao, the basal beds are variably conglomeratic. Usually the conglomerates are nonfossiliferous and probably nonmarine but Palmer does say that the Bulla shows "local presence of marine fossils". The use of the term "Bulla Conglomeratic Member" for the Baitoa facies seems questionable.

Stratigraphic sequence between López and Santiago.—Outcrops are discontinuous over this long stretch of the river and, due to lack of time, we were able to do only reconnaissance sampling of the most likely localities (Text-fig. 21). It was found that dips and strikes remained very constant at an average of 10° to the north and, using these, an attempt has been made to give the thickness of the section and the positions of our samples on the resulting column (Text-fig. 24). This calculation supposes that no significant faulting disturbs the sequence. Small normal faults with downthrow to the north are seen in some outcrops (for example, at Arroyo López and at La Barranca) but some antithetic faulting is also visible; these effects have been discounted in the calculation. Between the northern Arroyo Hondo (NMB loc. 17300) and Santiago the thickness of section is too doubtful to plot, as the geographical terrain suggests less constant dips and strikes. This is borne out by the measurements taken for three samples within the bounds of the city of Santiago where the dip is to the east (Text-fig. 22). If the calculation is correct, at least 1300 m of section is seen above the unconformity at López with another 200 m of section in Santiago itself.

At a point where Arroyo López joins the main river, two distinctive conglomerates separated by two m of clayey silt are seen, the lower one forming a prominent tilted island in the river (Text-fig. 26; Pl. 8, fig. 5). The surface of the island shows the bed to be a biogenic rubblemass with corals, echinoids and large molluscs



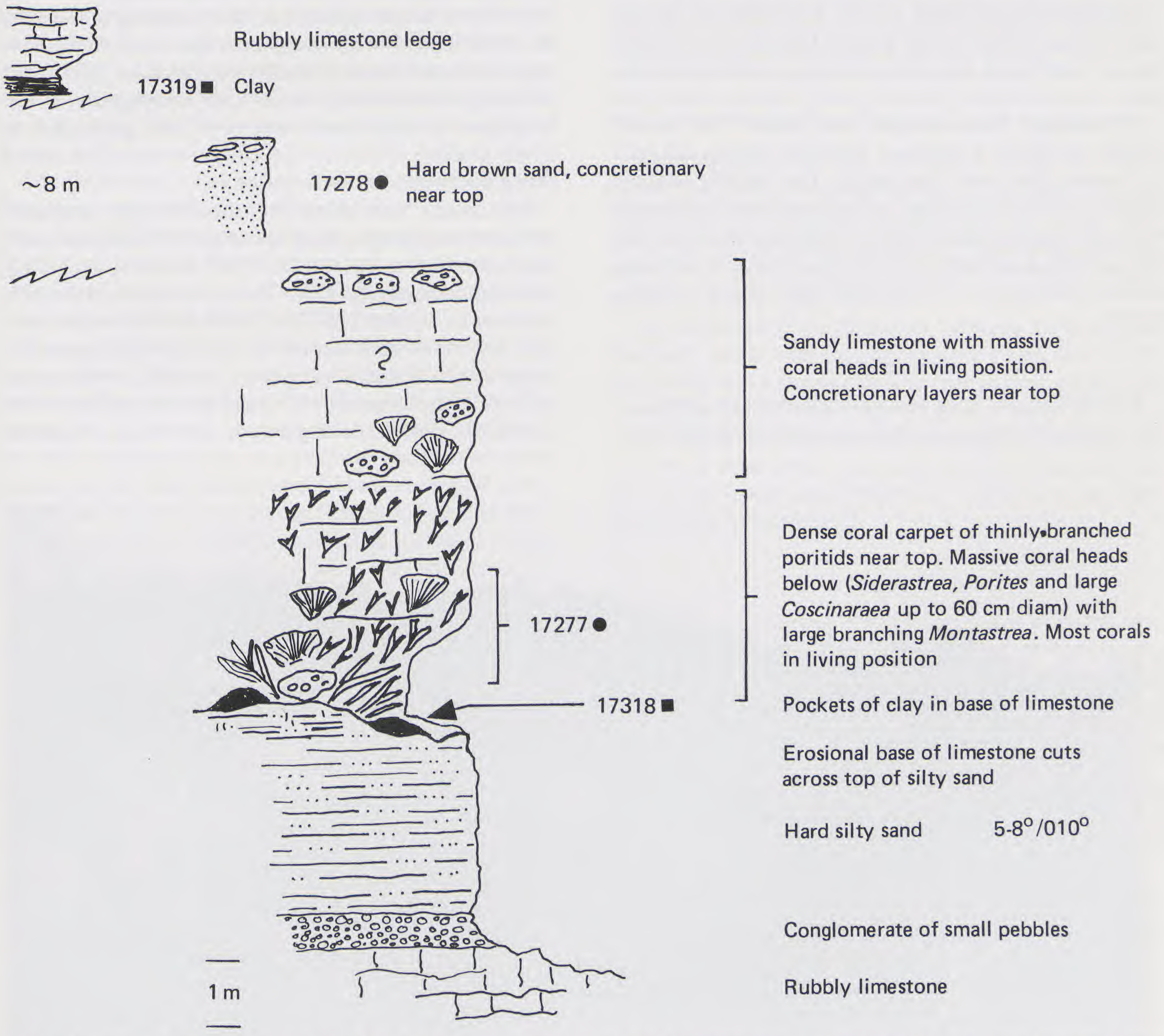
Text-figure 26.—Section at Arroyo López on Río Yaque del Norte, showing detail of exposures of highly fossiliferous conglomerate. Black squares represent NMB localities collected for microfossils and lithologic analyses; black circles represent NMB localities collected for macrofossils (see Text-fig. 21 for geographic positions of these localities). See also Plate 8, figure 5.

such as oysters and *Pecten* in a gritty matrix largely composed of the foraminifer *Amphistegina* and *Sphaerogypsina*. The lower part of the 1.5 m conglomerate contains igneous cobbles and pebbles while the sand below is strongly burrowed from its upper contact. This locality is incorrectly given as 'type loc Baitoa' by Bold (1968, text-fig. 6).

What we have called the "Angostura Gorge" is a well-marked feature on the topographic map and turns out to be so on the ground. We take it to be composed entirely of limestone, with perhaps very subordinate calcareous silts or sands, but we had time only to examine the base of the limestone at the upstream end and its top at the downstream end. Its thickness could be at least 300 m as calculated for Text-figure 24.

Text-figure 27 shows the situation at the upper end of the gorge and is interesting as it affords one of the few places known to us where the corals are almost all in position of growth and represent actual reef conditions. The corals appear to have grown on a paleosurface of silty sand. A few calcareous sands and clays some cross-bedded, can be seen above the basal limestone. Above these are limestone beds that are pebbly and have erosive bases. Downstream from these outcrops the river enters the main gorge.

The top of the limestone gorge is seen at the down-



Text-figure 27.—Composite section based on three exposures at the south end of a conspicuous limestone gorge ("Angostura Gorge") between López and Angostura on Río Yaque del Norte. Black squares represent NMB localities collected for microfossils and lithologic analyses; black circles represent NMB localities collected for macrofossils (see Text-fig. 21 for geographic positions of these localities).

stream end, at La Boca, where coral debris layers are interbedded with *Amphistegina*-rich silty sand with coral debris and casts of large gastropods and bivalves. The dip is locally as steep as 20° at this point, but this seems to be only a local steepening. Immediately to the north the valley widens in more uniform clayey silts rich in foraminifera and with scattered small molluscs and plant debris.

At La Barranca, cliffs on both sides of the river give good exposures in rather uniform silts with subordinate interbeds of silty sand and with discontinuous layers and minor lenses richer in shells. The dip remains at 10° just east of north. A number of small faults are visible with downthrows to the north.

A single sample (NMB 17300) was taken on the old valley slope further to the north (Text-fig. 23). It consists of weathered silt with scattered, rotted coral debris.

In Santiago, three samples were taken. The lowest (NMB 17293) is a uniform, massive, clayey silt rich in foraminifera and pteropods. The middle sample (NMB 17315) is in bedded, clayey and sandy siltstones while the highest one (NMB 17196) is a uniform silty clay. Taking a uniform easterly dip of 10°, the Santiago section amounts to a little more than 200 m of sediments.

Environment

Beds below the Miocene unconformity at López.—The conglomerates and sands exposed along the river, though poorly sorted, show repeated incomplete grading. Close to the unconformity the bedding is better developed and load casts are common. Frequent gravity inflow of shallow-water material (including coral heads) took place on a slope. Silt clasts containing relatively deep-water faunas were torn up and carried in with the shallow material. Some of the clasts show distorted bedding, suggesting that they were only semilithified when eroded and were therefore penecontemporaneous. This is important as the sequence has had to be dated on planktic foraminifera from the clasts.

Sampling in the cliffs at Baitoa (NMB locs. 17168–17170) is from somewhat lower in the section, as calculations suggest that the unconformable surface is cutting deeper in this direction. Here, finer-grained silts are interbedded with conglomerates, and these also suggest a water depth certainly greater than 100 m and probably considerably more. One incongruity is the finding of a single specimen of a land gastropod at NMB locality 16909 on the cliffs. Perhaps this was a living specimen that was rafted in.

The coarse beds below the unconformity represent the top of a sequence, predominantly of conglomerates, that is known to be at least 1700 m thick, according to measurements by IFP. This is in line with a calculation by Palmer (1979) of 2400 m. The major part of it may have been deposited during a time span not longer than two million years, probably with many periods of nondeposition. Considerable uplift of the Cordillera Central is suggested, providing a copious

Text-figure 28.—Photograph of cliff exposure on Río Yaque del Norte north of Baitoa, showing the discordant contact (black triangle) between the Baitoa Formation and the underlying Tabera Group. The inaccessible upper part of the cliff was designated as the type locality of the Baitoa Formation (Cooke, 1920). See Text-figure 21 for geographic position of this exposure.

supply of well-rounded, hard rocks that include predominant melanocratic igneous rocks, but also some leucocratic rocks and, at least at the top of the section, dark limestone boulders up to one m in long dimension. Although the major part of the section could have been deposited in two million years, as suggested above, the total time span for the complete conglomerate series in the Baitoa area could be as long as six million years, which is considerable when taking account of the whole known time span of the Cercado, Gurabo and Mao formations in the Río Gurabo and Río Cana (see Table 4).

Beds above the Miocene unconformity at López.—The first 14 m of badly-sorted, pebbly sands and conglomerates have abundant shallow-marine molluscs and hemispheric and encrusting coral heads, some of which were certainly growing in situ on the gravel flats in an environment that, when it remained stable, could provide clear, shallow-water conditions favorable to them.

The following six m of silt, richer in molluscs and bryozoans and with more foraminifera, again represents very shallow water as is borne out by the complete absence of planktic foraminifera and calcareous nannofossils. The numbers of miliolids suggest that the environment could have been lagoonal.

The remaining 34 m of the measured section are finer grained, but with varying energy levels as suggested by frequent influxes of pebbles and cobbles. The instability of the environment was noted by Dr. Geister, who recorded layers of cobbles overgrown by coral heads (mostly *Siderastrea* and *Coscinaraea* and some *Montastrea*) up to 0.5 m across. These beds were themselves covered by conglomerates that included rolled and broken, massive corals of the same species, with some debris of branching corals (*Stylophora* sp.).

The silts are heavily burrowed and rich in smaller molluscs and also in soritid foraminifera. The latter are thought to have lived on the fronds of sea grasses such as *Thalassia,* which almost certainly covered the sandy bottom much of the time. Lignites are not seen but woody fragments, including several pieces of tree branches, are common. Planktic foraminifera and calcareous nannofossils are still excluded from this very shallow-water marine environment.

Stratigraphic sequence between López and Santiago.—The sequence of beds at Arroyo López (Text-fig. 26) indicates conditions rather similar to those discussed above in the López section. The silts carry an *Ammonia/Elphidium* foraminiferal fauna, showing a brackish influence. The rubble bed that forms the island suggests clear, shallow water with enough movement to winnow out all the fines. The richness of large irregular echinoids is unusual.

At the south end of the "Angostura Gorge," the base of the limestone section was visited (Text-fig. 27). Its main interest lies in the environmental information given by the corals about which Dr. Geister (written commun., 1984) has provided the following notes:

> At the entrance of the Angostura gorge a true coral framework of about 3 m thickness has been recognized [NMB locality 17277]. Dense stands of an unusually branching species of *Monastrea* along with numerous branching poritids, massive *Siderastrea, Porites* and ? *Coscinaraea* (up to 60 cm across) are comparable to well developed coral formations found today in many thriving Caribbean fringing and patch reefs. Since most of the corals are encountered *in situ* this is certainly the best example of a true reef formation found up to now in the Neogene of the Gurabo, Cana and Yaque del Norte river sections. Due to the limited outcrop area examined, it cannot be decided if it is a patch reef or just an extensive coral carpet. The systematic composition of the coral fauna does not provide good bathymetric criteria. However, the general appearance of the densely packed corals with several massive species that do not show a flattened growth habit suggests a depth shallower than 20 m. Several of the massive species would be expected to have developed a flattened growth habit when found below this depth on living reefs.

Unfortunately, we had no time to study the limestones that form the gorge itself. At La Boca, the top limestones are followed immediately by clayey silts with rich foraminiferal fauna showing a high ratio of planktic to benthic species indicative of deeper water, probably greater than 100 m.

The outcrops at La Barranca, between La Boca and Santiago, are of silts that again have a rich foraminiferal fauna with a strong planktic component, suggesting a continuation of water depths greater than 100 m.

The three samples taken in Santiago (Text-figs. 22, 24) are all deep water with rich planktic foraminiferal faunas; the lowest one (NMB loc. 17293) is a clay that is also rich in pteropods.

Age

The great thickness of conglomerates exposed upstream from Baitoa has been dated at several levels by Dr. Carla Müller. All samples are of NP24 Zone, middle Oligocene age.

The cliffs at Baitoa (NMB samples 17168–17170) contain a flora of NP24 Zone, middle Oligocene. Planktic foraminifera agree with a late middle Oligocene or late Oligocene age. Rare specimens of *Globigerinoides primordius* Blow and Banner, 1962, are present.

Immediately under the unconformity in the López section (labelled "horizon A" on Text-fig. 25), NMB samples 17320, 17321, and 17193 from silty clay clasts within the conglomerates have yielded planktic foraminifera. *Globigerinoides primordius* is commoner here and the fauna places the clasts at approximately the Oligocene–Miocene boundary. This is supported by the nannofossils in NMB sample 17321, which give a date probably near the top of the NN25 Zone. It must

be remembered that this dating is on resedimented clasts that might represent a somewhat older age than the matrix.

The section at López above the unconformity, designated as a hypostratotype for the Baitoa Formation, has not been dated by planktic foraminifera or nannofossils but Dr. W. A. van den Bold reports that NMB samples 17186 to 17190 belong to his *Aurila amygdala* Subzone on ostracodes, the range of which would be from *Globigerinatella insueta* Zone to *Globorotalia fohsi* Zone, based on planktic foraminifera, and therefore of late early to early middle Miocene. This is an important finding as the base of the Cercado Formation on the unconformity in the Río Gurabo, where it can be dated on nannofossils is NN11 Zone, late Miocene.

The results on ostracodes are in good agreement with Vokes (1979), who dated the Baitoa Formation as late early Miocene (Burdigalian) by using the concurrent ranges of several species of gastropods.

The section downstream on the Río Yaque continues to have been deposited under inshore conditions and has not been dated on foraminifera or nannofossils between López and the north end of the "Angostura Gorge". However, NMB samples 17316 and 17317 at Arroyo López are thought to be late Miocene by Dr. van den Bold. Text-figure 24 places the various outcrop sections in their correct positions if no significant faulting has taken place. This shows that the thickness of section between the López section and Arroyo López is not great, though a concealed unconformity between the two cannot be ruled out.

It must also be mentioned that Dr. J. Geister has identified the coral genus *Coscinaraea* in samples at López (NMB loc. 16943), Arroyo López (NMB loc. 17274) and at the base of the limestones that form the "Angostura Gorge" (NMB loc. 17277). The range of this genus in the Caribbean region as determined in Chiapas (Frost and Langenheim, 1974; Frost, 1977) is from the base of the Miocene to the early part of the middle Miocene. This would agree with evidence given above for the age of the Baitoa Formation but would conflict with the presumed age of the section between López and La Boca. This question remains unresolved at the moment.

At the top of the limestone section at La Boca, the silts are of *Globorotalia margaritae* Zone age with one sample (NMB loc. 17295) containing dextrally-coiled *G. margaritae*. Such a level is known elsewhere in the Caribbean close to the base of the zone (Bolli and Saunders, 1985) and thus we draw the Miocene/Pliocene boundary at about the top of the limestones. Determination of the upper part of the NN11 Zone, based on nannofossils from the same samples, gives reasonable support to this conclusion.

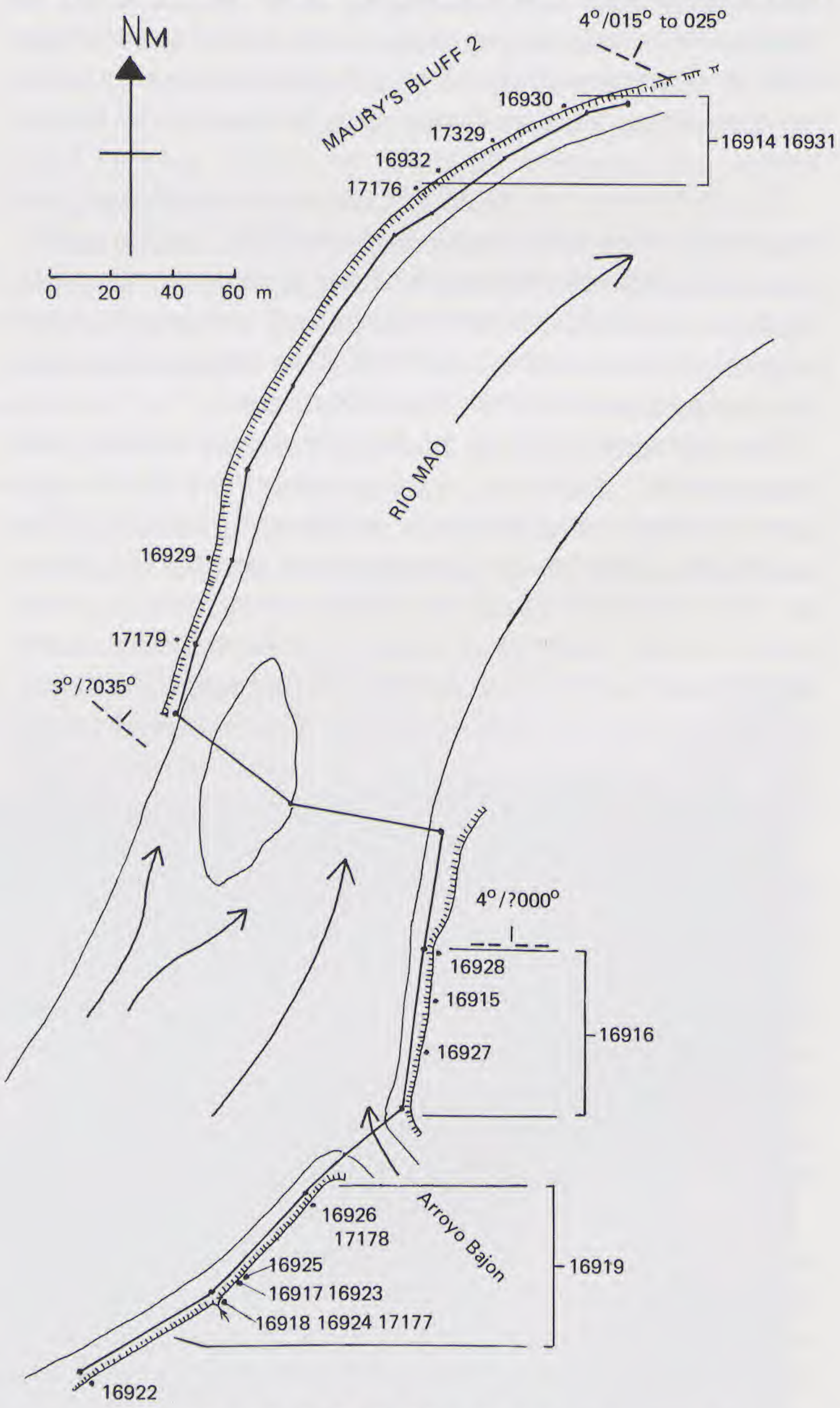
Samples higher in the section, at La Barranca, Arroyo Hondo and in Santiago itself, mostly give good determinations of the upper part of the *Globorotalia margaritae* Zone (*i.e.*, equivalent to the *G. margaritae evoluta* Subzone) and would be classed as late early Pliocene according to our classification (Table 4). Determinations of NN13 to NN15 zones, based on nannofossils, are in agreement.

We see from the above that the Río Yaque section does not reach stratigraphically as high as the sections seen in the Río Cana and Río Gurabo.

Río Mao

General

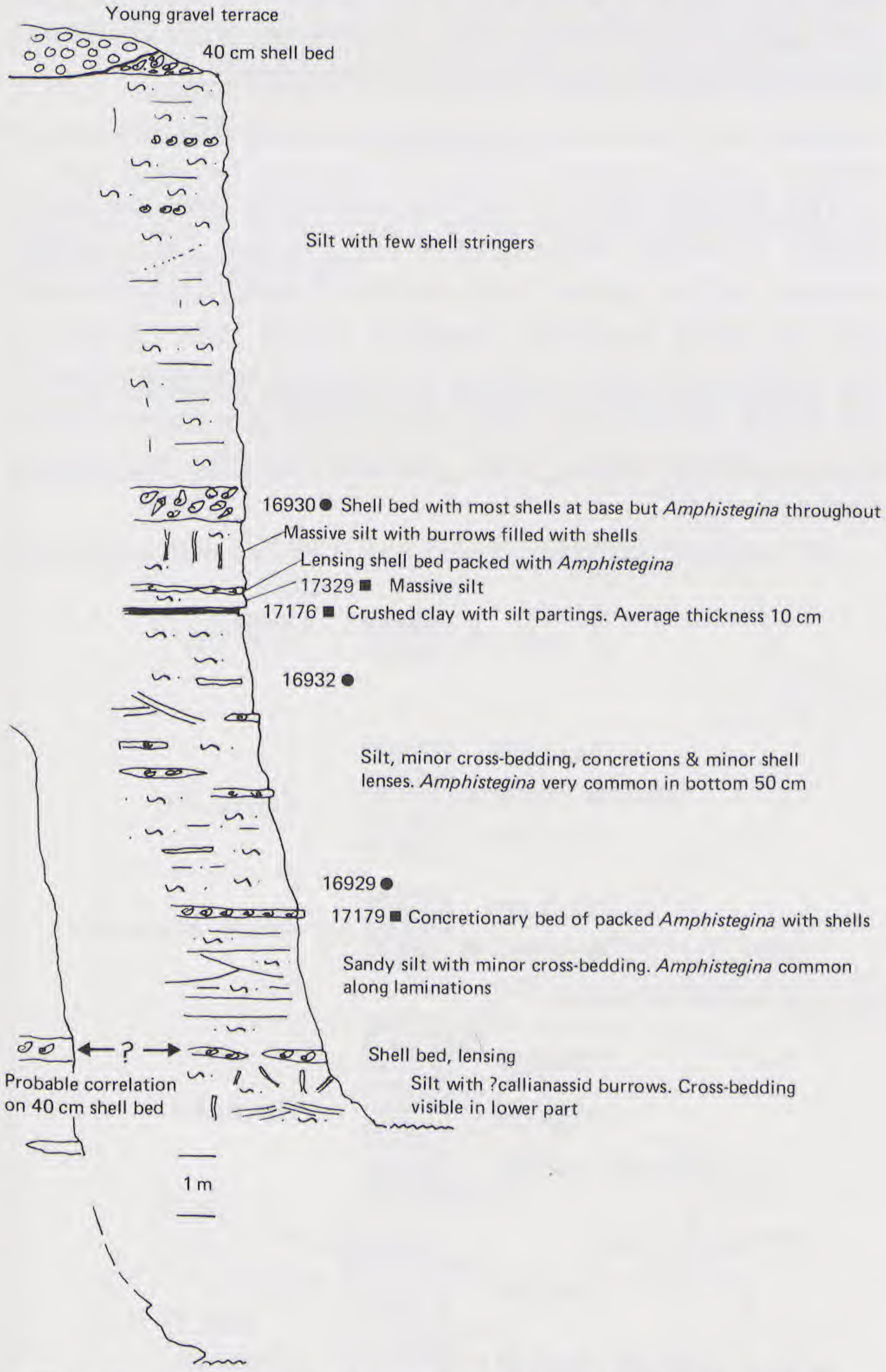
It was realized that we should not be able to do any



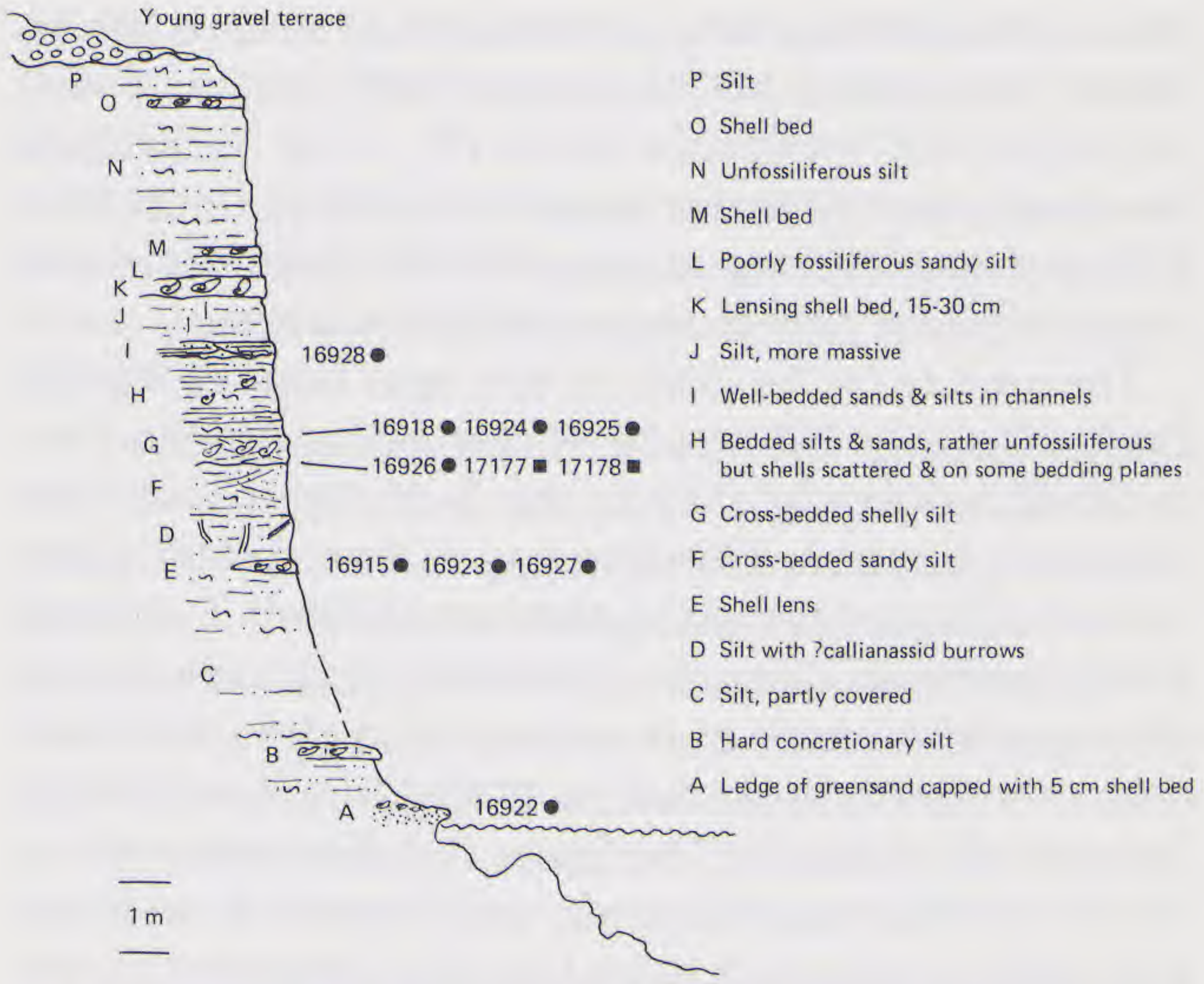
Text-figure 30.—Map of Río Mao (based on tape and compass survey), showing geographic positions of NMB collecting localities from Maury's Bluff 2 and the right bank cliff at the mouth of Arroyo Bajón.

extensive sampling in the Río Mao, as this is a river section of great length with formidable cliffs showing negligible dip (Pl. 8, fig. 1), separated by long stretches with no outcrops. To construct a meaningful stratigraphic column under such circumstances is not possible. We therefore concentrated on re-examining Maury's Bluffs 1, 2 and 3 in an attempt to date them and to collect discrete levels within them. Seven samples were taken for microfossils, 25 for macrofossils. The lower part of Text-figure 29 shows the area on which we concentrated and the map is extended northwards to document the position of U.S. Geological Survey (USGS) and Tulane (TU) localities.

Bluffs 2 and 3 are illustrated in Text-figures 30 to 33, of which Text-figure 30 is a map drawn on a tape



Text-figure 31.—Section exposed in Maury's Bluff 2 on Río Mao. Inset section at lower left represents section exposed across the river at Arroyo Bajón (see Text-fig. 32), and shows the probable correlation of the two sections, based on a 40 cm shell bed. Black squares represent NMB localities collected for microfossils and lithologic analyses; black circles represent NMB localities collected for macrofossils. See Text-figure 29 for geographic position of this section. See also Plate 7.

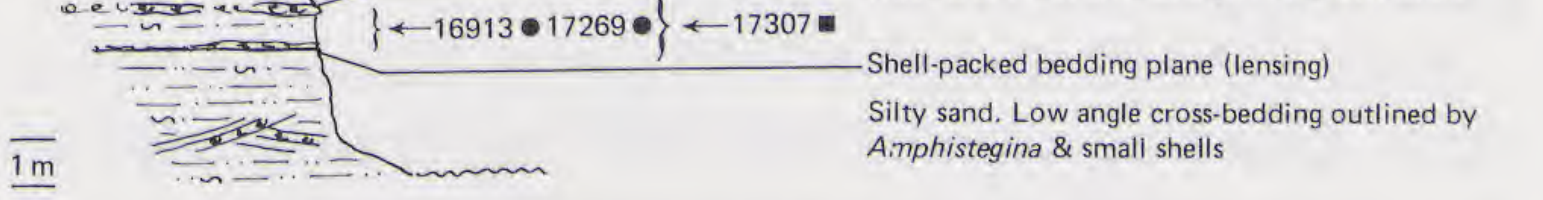


Text-figure 32.—Section exposed at the mouth of Arroyo Bajón on Río Mao, showing lithological details and stratigraphic positions of NMB collecting localities. Black squares represent NMB localities collected for microfossils and lithologic analyses; black circles represent NMB localities collected for macrofossils. The shell bed on which correlation across the river to Maury's Bluff 2 was based (see Text-fig. 31) is here indicated by "G". See Text-figure 29 for geographic position of this section.

and compass survey of Bluff 2 and its continuation on the right bank at the mouth of the Arroyo Bajón.

Lithology

Bluff 3 is the furthest upstream. Only the eastern end of this huge, curving cliff was studied (Pl. 7, fig. 3; Text-fig. 33). This is in the strike of the beds at approximately 280° (magnetic); the dip is only a few degrees to the north and so it would appear that there is a partial stratigraphic overlap with Bluff 2 and its continuation at the mouth of Arroyo Bajón. Silty sands



Text-figure 33.—Section exposed at the downstream (eastern) end of Maury's Bluff 3 on Río Mao, showing lithological details and stratigraphic positions of NMB collecting localities. Black squares represent NMB localities collected for microfossils and lithologic analyses; black circles represent NMB localities collected for macrofossils. See Text-figure 29 for geographic position of this section. See also Plate 7.

have cross-bedding that is prominent at some horizons where it is picked out by lines of pink shells of *Amphistegina* and molluscan debris (Pl. 7, fig. 4). Though the sands are relatively massive, bedding is obvious from a distance being accentuated by wisps, lines and lenses of shells and by secondary concretions.

The section in the cliffs on the right bank at Arroyo Bajón (Text-fig. 32) can be continued across the river in Bluff 2 (Text-fig. 31) as the 3–4° dip allows slow progress upsection. The lithology of these differs slightly from what is seen along the base of Bluff 3. In Bluff 2/Arroyo Bajón, there is somewhat more variation in lithology from sands to occasional thin clays with bedding more prominent but cross-bedding less well-developed (Pl. 7, fig. 1). The fauna is richer with beds up to 50 cm thick packed with well-preserved molluscs and shells of *Amphistegina*. One such secondarily calcified layer is illustrated in Plate 7, figure 2. Shell-filled burrows are frequently visible.

Bluff 1 (Pl. 8, figs. 1, 2) consists of uniform silts in the lower part with lines of concretions. Fossils were found scattered throughout and in lenses but the latter did not prove to be as rich as those of Bluffs 2 and 3.

Between Bluffs 1 and 2 the track along the right bank passes at the foot of a steep slope overgrown with trees and capped by a cliff from which blocks of limestone had fallen. These were principally of interest for their corals (NMB loc. 16911).

Environment

The silts and silty sands with shell lenses seem to be of very shallow-water origin at Bluff 3 and Bluff 2. Going upsection, Bluff 1 suggests more open marine conditions with planktic foraminifera and calcareous nannofossils beginning to make their appearance.

The isolated sample at the Mao Clay type locality (TU loc. 1337) is deeper water with a rich planktic component.

Age

Bluff 3 and the Arroyo Bajón bluff have so far produced no dates based on calcareous nannofossils and planktic foraminifera.

Bluff 2 has given a weak determination of late Miocene, NN11 Zone, based on nannofossils (NMB sample 17329).

Bluff 1 (NMB sample 17175) is late Miocene, NN11 Zone, based on nannofossils and this is supported by the coiling ratio of menardiform Globorotalias.

A sample from the Mao Clay type locality supplied by Dr. Emily Vokes (TU loc. 1337) is NN16 Zone, based on nannofossils and has a rich planktic foraminiferal fauna of *Globorotalia exilis* Subzone of the *Globorotalia miocenica* Zone, late middle Pliocene. These two determinations agree well.

Río Amina

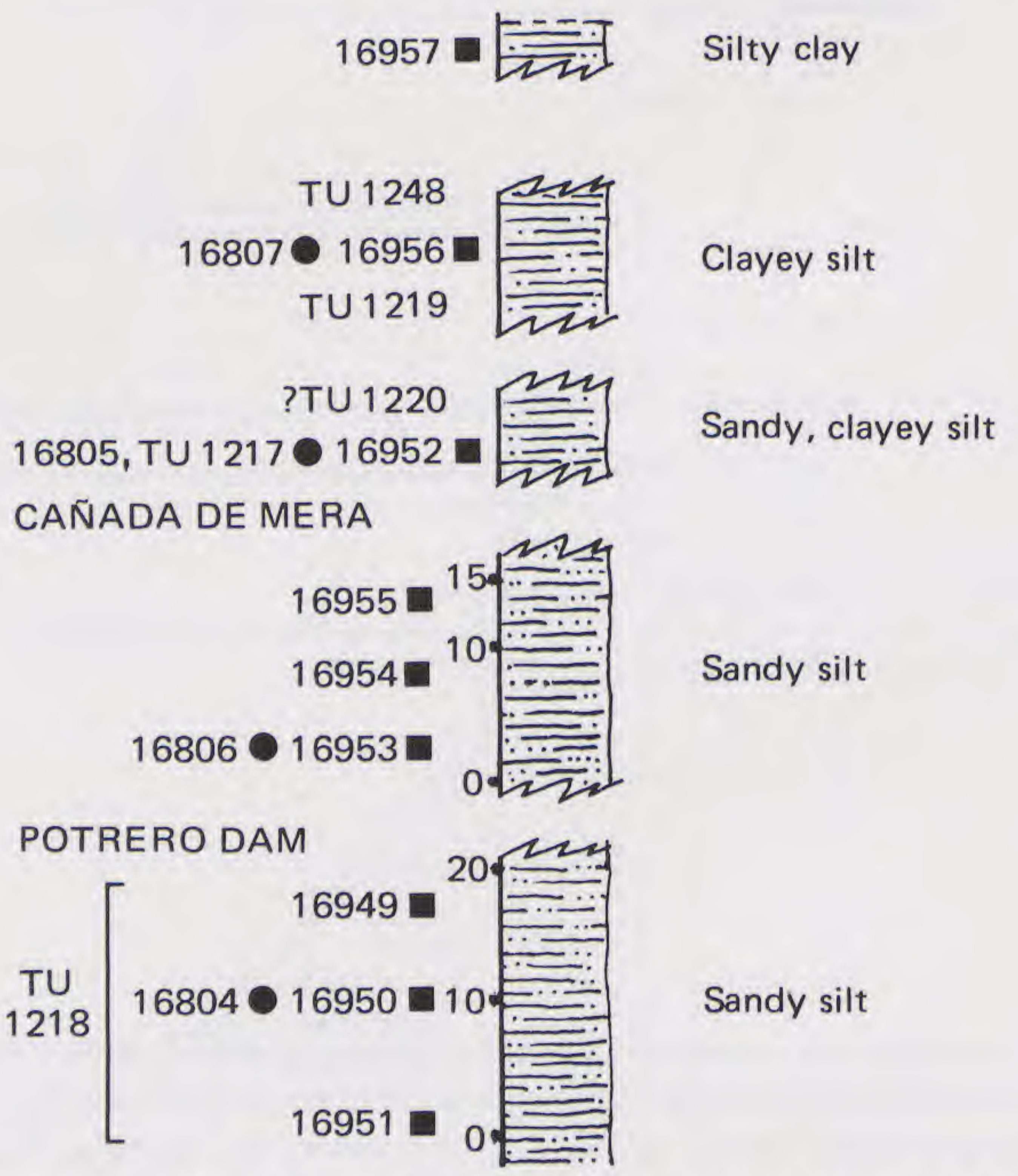
General

We had intended to sample extensively in the Río Amina but, after a reconnaissance of the river above the Potrero Dam, it was apparent that the logistic problems would not allow us to do any meaningful work in the time available. One disadvantage is access in this part of the river and also the distance that has to be covered to gain any appreciable thickness of section, as the dip is negligible. We sampled a few localities in the middle reaches of the river and these are plotted on Text-figure 34. The individual measured sections are separated on the column (Text-fig. 35). Though they are thought to be stacked in the right order stratigraphically, the amount of section between each outcrop area is uncertain. Only 10 samples were collected for microfossils and four for macrofossils.

Lithology

The general trend is for the section to become more clayey upwards, beginning at the Potrero Dam where a sandy silt is packed with shells of *Amphistegina* and rich in small molluscs. Solitary corals were noted in the Cañada de Mera where the overall lithology is still the same. Downriver, silty clays contain a more varied foraminiferal fauna with planktic species becoming common.

An isolated sample (NMB loc. 16958) was collected



Text-figure 35.—Schematic column for the central portion of Río Amina, showing relative stratigraphic positions of NMB and TU collecting localities. Black squares represent NMB localities collected for microfossils and lithologic analyses; black circles represent NMB localities collected for macrofossils.

on the road from Mao to Santiago south of the Río Yaque at its junction with the road to Potrero Dam; this is 5.5 km northeast of the dam and 1 km west of Guatapanal (Dominican Republic Grid ref. BM 577973). The lithology is a subconchoidally-fracturing clayey silt with microfauna and scattered stick corals. This seems to be equivalent to TU locality 1216.

Environment

The samples taken in the Río Amina were all fine grained. Those at Potrero Dam suggest open marine but inshore conditions, the weak planktic foraminiferal component comprising those species normally found closest to the coast (*e.g., Globigerinoides* spp.). The evidence suggests slow deepening upwards. At NMB locality 16956, 25% of the foraminiferal fauna is planktic, but species of *Globorotalia* are virtually absent. By NMB locality 16957, a deeper assemblage has 90% planktics with species of *Globorotalia* well in evidence.

The isolated younger sample at NMB locality 16958 carries a good, deep-water, open-marine assemblage of planktic foraminifera.

Age

The series of samples at Potrero Dam has given no positive result on foraminifera, but the highest locality (NMB sample 16949) has a poor flora of possible NN12 Zone age.

Most other samples taken downriver and considered to be upsection give almost no age results on planktic forms except for NMB sample 16952, which is again ?NN12 Zone.

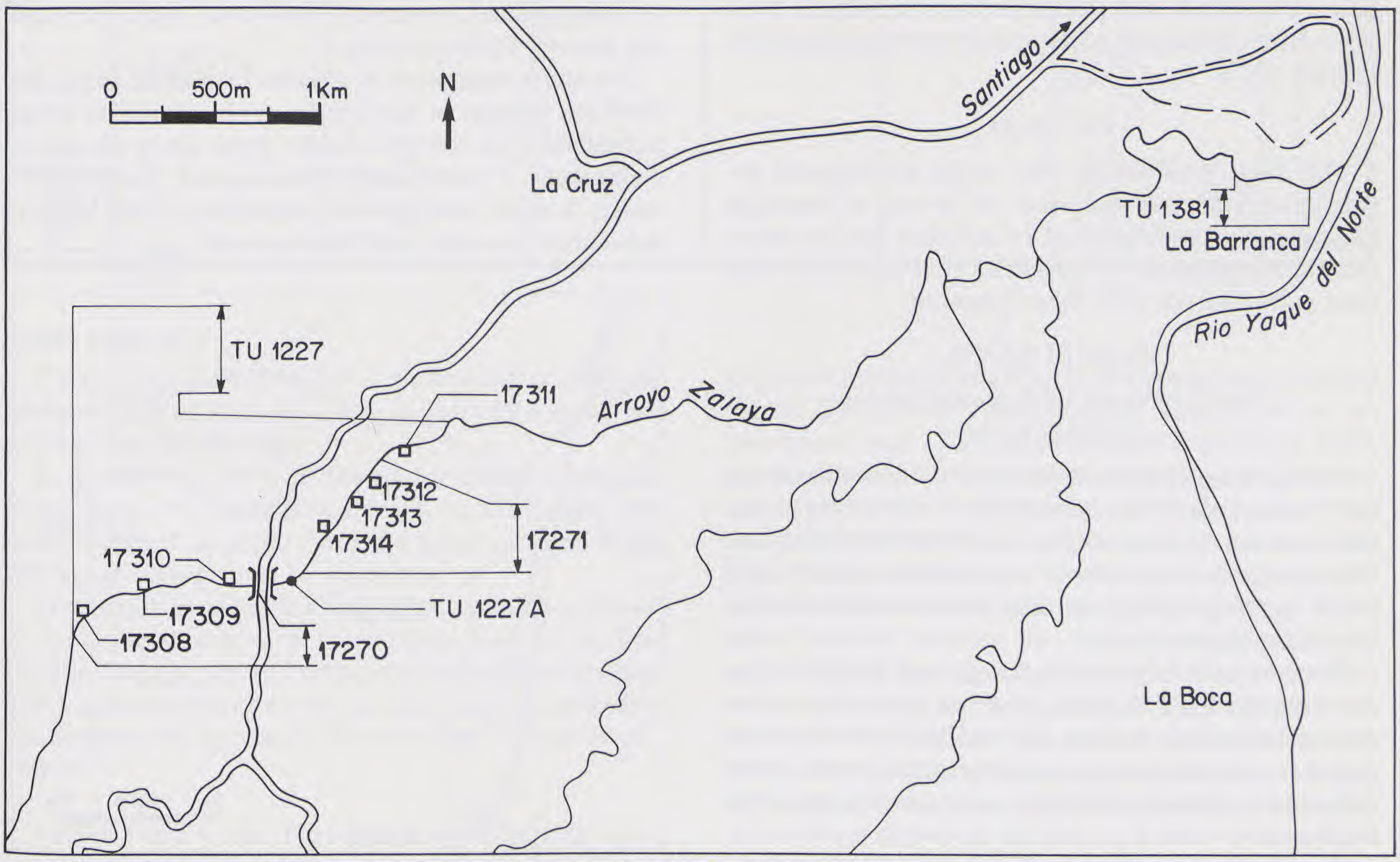
The highest sample (NMB loc. 16957), in an isolated outcrop on the river, has a rich NN12 Zone flora and a rich *Globorotalia margaritae* Zone fauna. The dominance of sinistrally-coiling menardiform Globorotalias would place the sample almost at the base of the zone and, therefore, at the base of the Pliocene; the determination of NN12 would support this.

The isolated NMB sample 16958 taken at the road junction is either from the upper part of the *Globorotalia margaritae* Zone or the lower part of the *Globorotalia miocenica* Zone, and a revised estimate of approximately NN15 Zone, based on nannofossils would agree with this determination.

Arroyo Zalaya

General

The road from Santiago to Janico crosses the Arroyo Zalaya about 9 km south of the city. We collected



Text-figure 36.—Map of Cañada Zalaya (area 5 of Text-fig. 3), showing geographic positions of NMB and TU collecting localities. Open squares represent NMB localities collected for microfossils and lithologic analyses.

samples and made a rough survey of a stretch of the stream course above and below the bridge (Text-fig. 36). Above the bridge, some of the strikes are rather irregular but the overall trend is 10–15° due north, which fits the regional pattern seen in the Río Yaque 4 km to the east. The overall lithology is a silt with minor shell beds, minor conglomeratic lenses and, at the eastern end of the traverse (upper part of section), more strongly lignitic silts and sands.

Environment

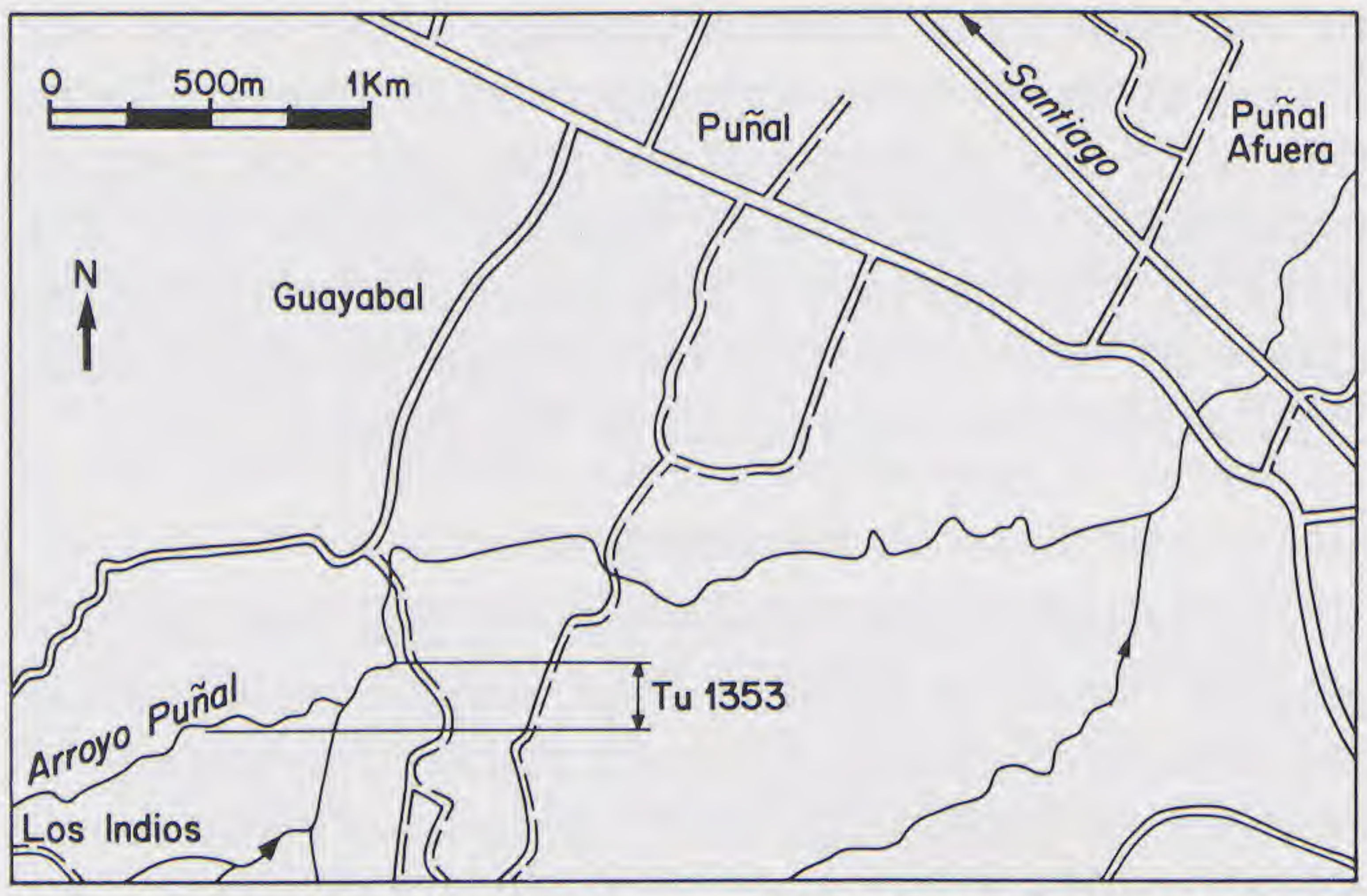
The relatively rich foraminiferal faunas suggest open marine conditions with moderate water depths. Relatively low energy levels allowed the deposition of lignitic silts and sands near the top of the section.

Age

Rather sparse results on nannofossils suggest a probable early Pliocene age. NMB sample 17312 has a good planktic foraminiferal fauna of *Globorotalia margaritae* Zone, early Pliocene age, and is probably from the upper part of the zone.

Arroyo Puñal

The Arroyo Puñal area is situated approximately 12 km southeast of the city of Santiago (Text-fig. 3). We have not visited these outcrops and Text-figure 37 is given here exclusively to document the location of TU locality 1353.



Text-figure 37.—Map of Arroyo Puñal (area 8 of Text-fig. 3), showing geographic position of TU locality 1353.

Río Verde

The fossil localities on Río Verde are situated approximately 21 km southeast of the city of Santiago (Text-fig. 3). Text-figure 38 is included here to document the location of TU localities 1250 and 1251. Our field party did not visit these localities.

CONCLUSIONS

Late Tertiary Geography of the Cibao Valley

During the geological time interval under discussion the Cibao Valley was apparently occupied by a sea-filled graben backed to the south by the Cordillera Central and perhaps closed or partially closed to the north by land across the area now occupied by the Cordillera Septentrional.

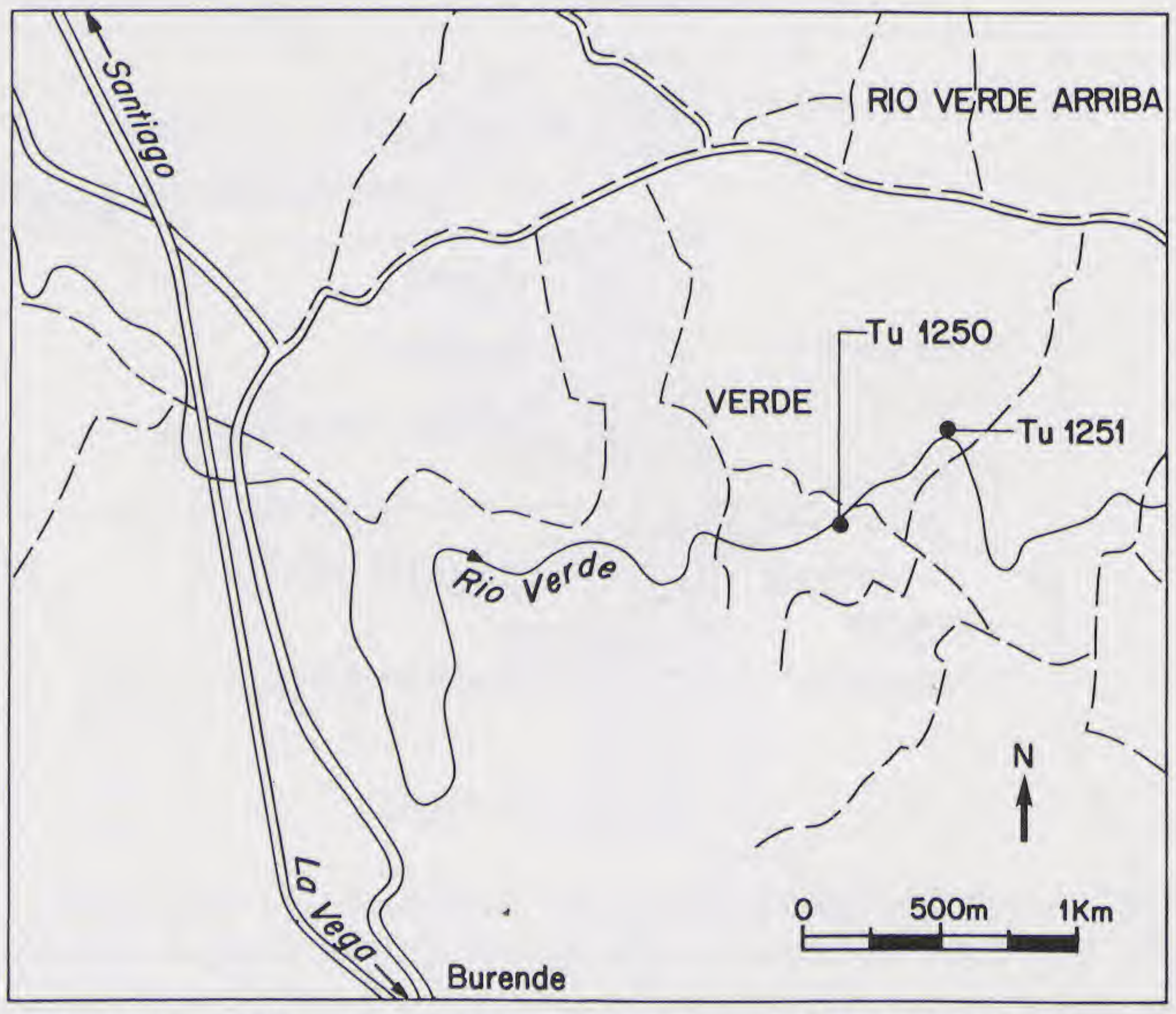
The southern edge of the trough was steepened by down-to-the-basin faulting that was probably active during deposition. In fact, the tectonic activity of the region is reflected in some of the structures seen in the sediments, especially the large amount of redeposited sediment.

The trough lies within the deformed belt that marks the northern limit of the Caribbean Plate and is still today within an area of shallow earthquake activity (Case and Holcombe, 1980).

The Cordillera Central provided a plentiful supply of clastic material, much of the coarser perhaps being second generation components that were derived from earlier conglomerates and thus were already rounded.

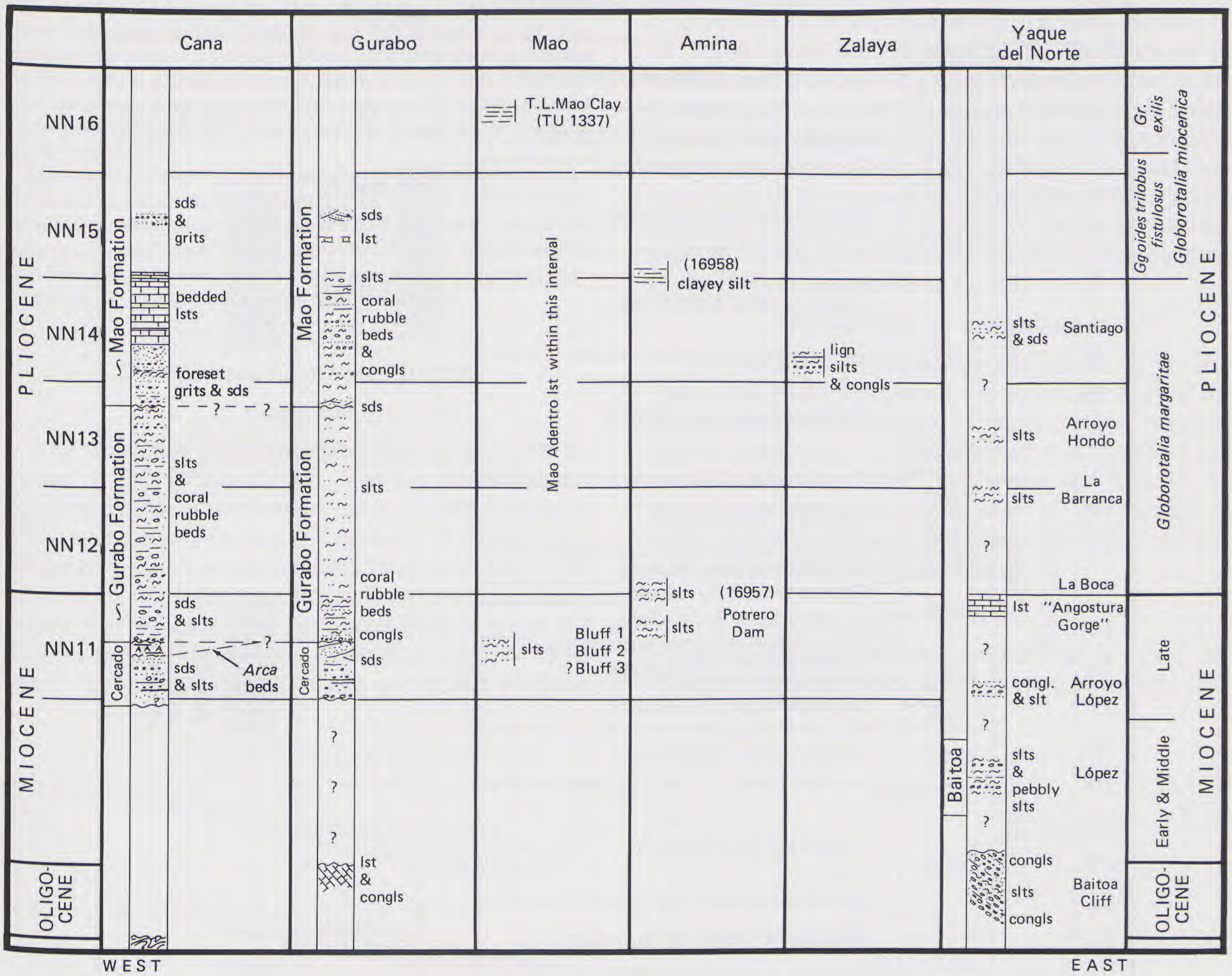
The sparsity of mangrove pollen in Río Gurabo samples suggests an absence of brackish water swamps along the coast though the dominance of ferns with palms could result from freshwater swamps backed by quickly rising ground, covered by savanna vegetation and not heavily forest-covered.

The main suggestion is of great instability along the southern margin of the trough, with sediments being periodically moved into deeper water down an appreciable slope. A stable shelf is missing and, though water clarity favored coral growth, instability of the bottom prevented luxuriant reef development.



Text-figure 38.—Map of Río Verde (area 9 of Text-fig. 3), showing geographic positions of TU localities 1250 and 1251 (black circles).

Table 3.—Stratigraphic sections from six of the river valleys studied for this project, showing approximate correlations. The sections are arranged in geographic order, *i.e.*, left to right = west to east.



There is no clear proof of a shallowing or infilling of the trough at least as late as middle Pliocence; the reverse may be the case.

Evidence is in favor of the major source of supply being from the Cordillera Central to the south, but some influx of material from the north or even along the trough axis cannot be ruled out.

The importance of the Cordillera Central as a source of supply is also seen on its southern side, in the Enriquillo Trough, where a turbiditic sequence more than 3000 m thick is found in the late Miocene and probably continuing into the early Pliocene (Biju-Duval *et al.*, 1982).

Tables 3 and 4 and Text-figure 39 attempt to summarize what is known at this stage of the project. Table 3 relates the three major river sections studied, and the more scattered localities in the other rivers, against a time framework which must be considered as approximate only. The zonation used is given in Table 4, which is drawn to a linear time scale to show better the relationship of the various lithologic units. Text-figure 39 draws attention to the situation of two of the important river sections in relation to the geography of the southern flank of the trough through time. It has been included because the vertical stratigraphic columns of Text-figures 6 and 16 give a false impression of the upward change in facies, ignoring the large northward shift in location. The separate slice shows some of the lateral facies changes between the two sections. Although the sequence in the Río Cana containing the *Arca* beds is shown on the slice, it is likely that it would not have extended that far into the trough. Oversimplification seems inevitable in this figure.

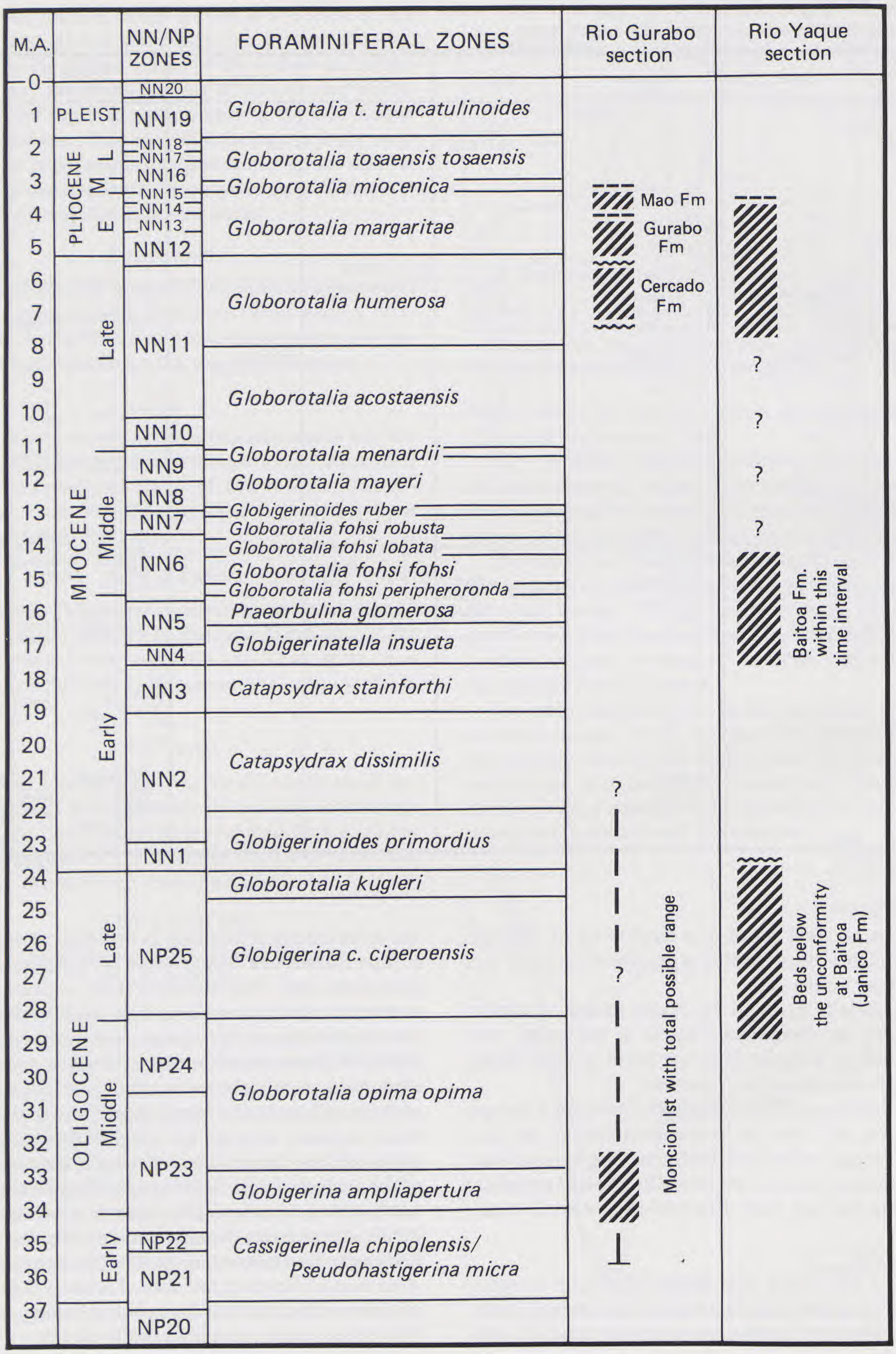

M.A.
NN/NP ZONES
FORAMINIFERAL ZONES
Rio Gurabo section
Rio Yaque section
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 32 33 34 35 36 37
PLEIST
PLIOCENE
L M E
MIOCENE
Late Middle Early
OLIGOCENE
Late Middle Early
NN20
NN19
NN18
NN17
NN16
NN15
NN14
NN13
NN12
NN11
NN10
NN9
NN8
NN7
NN6
NN5
NN4
NN3
NN2
NN1
NP25
NP24
NP23
NP22
NP21
NP20
Globorotalia t. truncatulinoides
Globorotalia tosaensis tosaensis
Globorotalia miocenica
Globorotalia margaritae
Globorotalia humerosa
Globorotalia acostaensis
Globorotalia menardii
Globorotalia mayeri
Globigerinoides ruber
Globorotalia fohsi robusta
Globorotalia fohsi lobata
Globorotalia fohsi fohsi
Globorotalia fohsi peripheroronda
Praeorbulina glomerosa
Globigerinatella insueta
Catapsydrax stainforthi
Catapsydrax dissimilis
Globigerinoides primordius
Globorotalia kugleri
Globigerina c. ciperoensis
Globorotalia opima opima
Globigerina ampliapertura
Cassigerinella chipolensis/ Pseudohastigerina micra
Mao Fm
Gurabo Fm
Cercado Fm
Moncion lst with total possible range
Baitoa Fm. within this time interval
Beds below the unconformity at Baitoa (Janico Fm)

Table 4.—Planktic foraminiferal (NP) and nannofossil (NN) zones, and absolute ages of Neogene strata in the Río Gurabo and Río Yaque del Norte sections. The equivalence of the NP and NN zones is largely after Bolli, Saunders, and Perch-Nielsen (1985). The juxtaposition of these zonations with the linear time scale (in millions of years B.P.) is calculated from Berggren *et al.* (in press). This use of a linear time scale shows the time ranges of the sediments seen in the field, and particularly emphasizes the magnitude of the major unconformities.

Space does not allow the subdivision of the *Globorotalia miocenica* Zone into an upper *Globorotalia exilis* Subzone and a lower *Globigerinoides trilobus fistulosus* Subzone. The *Globorotalia margaritae* Zone is also subdivided into an upper *Globorotalia margaritae evoluta* Subzone and a lower *Globorotalia margaritae margaritae* Subzone, but this subdivision has not been made here.

GENERALIZED GEOLOGIC HISTORY

Oligocene

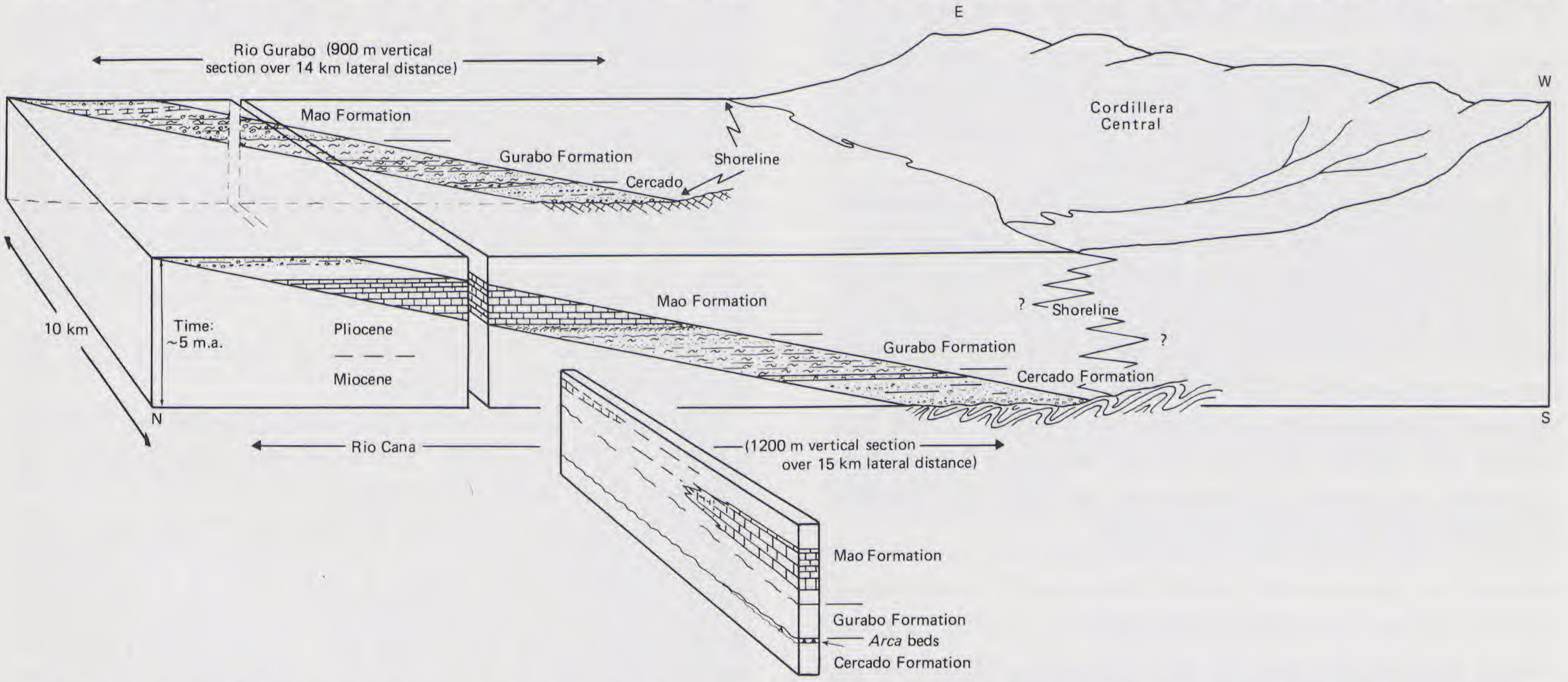
The Oligocene rocks are rather loosely grouped together in the Tabera Group. Various lithologies are involved, from limestones to suites of conglomerates. Varying degrees of folding and planation followed their deposition but these movements should be seen in the context of the long time interval represented everywhere that we have seen the unconformity below the Miocene and younger series. In the Río Cana, the 'basement' rocks are of unknown age. In the Río Gurabo, the limestones are of probable Oligocene age though they could reach as high as early Miocene. This gives a minimum time represented by the karst surface of 12 million years and, more probably, as much as 20 million years. In the Río Yaque del Norte, an intermediate series of rocks (the Baitoa Formation) is found between the conglomerates of the Janico Formation and the late Miocene age equivalents of the basal Cercado beds in the western river sections. There is still room for a time gap of several million years as represented by the erosional surface that is well displayed in the cliffs at Baitoa (Text-fig. 28).

Middle Part of the Miocene

The sediments of the Baitoa Formation on the Río Yaque del Norte are considered to occupy part of the time interval between basal Miocene and late Miocene that is represented by unconformities in the Río Cana and Río Gurabo. Either this was a low area in the tectonically active southern edge of the trough, or equivalent deposits were laid down but later removed from other segments of the margin.

Late Miocene

The beds above the basal unconformity in the Río Cana are unfossiliferous and may even have been non-



Text-figure 39.—Block diagram showing the relationship between Neogene sections on Río Gurabo and Río Cana. The sedimentary record reflects a deepening that is partly due to increasing distance from the shoreline as one proceeds downriver. The lithologic differences between the two columns (only 10 km apart along strike) are apparent. Some aspects of this variation are shown on the block slice, where the disappearance of the thick limestone mass seen in Río Cana is shown as a possible wedge-out, with new minor limestones coming in at a slightly higher stratigraphic level in Río Gurabo. A possible wedge-out of the section containing the *Arca* beds is shown on the block slice, though this lithology may not have extended as far north into the trough as is suggested.

Showing the position of the shoreline through time is hypothetical, as its repeated oscillations due to regressions and transgressions in the framework of a subsiding trough are difficult to forecast from the information at hand. A rapidly-rising sea level at the Miocene–Pliocene boundary seems very likely, and this is reflected particularly in the deeper-water facies of the Río Gurabo section at this time. This is why we show the shoreline further south at the east edge of the block. A comparative amount of deepening is not seen in the Río Cana; perhaps this reflects variable subsidence along the length of the trough.

marine in origin. The earliest beds in the Río Gurabo are, in contrast, already shallow marine with some possible brackish influence. Moving upwards in the Río Cana very shallow marine deposits have occasional shell and coral debris and are succeeded by a series of sands and silts containing a number of *Arca* beds arranged partly in rhythmic sequences. This interval is largely represented by the cross-bedded *Amphistegina* sands of the Río Gurabo.

An interesting possibility suggested by preliminary ostracode datum points supplied by Dr. van den Bold and plotted here in Table 2 is that the part of the section containing the *Arca* beds themselves in the Río Cana is missing in the Río Gurabo because it has been cut out by erosional overstep of the basal conglomerate of the Gurabo Formation. Such a possibility is indicated in Table 3 and on the block diagram (Text-fig. 39). In the Río Cana the distance between the first occurrence of *Gangamocerithidea*? *plicata* + *Cytherella* A and the first occurrence of *Radimella* is 117 m whereas in the Río Gurabo the distance has shrunk to 14 m, occupied predominantly by the basal conglomerate of the Gurabo Formation.

The position of the shallow-marine silts and sands of Maury's Bluffs 2 and 3 in the Río Mao is uncertain, but they could be equivalent to the *Amphistegina* sands of the upper Cercado Formation or of those in the lower Gurabo Formation. The Arroyo López rubble bed on the Río Yaque del Norte is also not well tied down within the late Miocene, where it is placed at the moment on rather doubtful evidence.

The latest Miocene in the Río Cana seems condensed in comparison with other sections. It remains very shallow and certainly has a number of hiatuses within it. In the Río Gurabo the interval is represented by a sequence of fossiliferous silts with frequent interbeds that are particularly rich in corals, most of which show signs of displacement, probably on a slope. In the Río Yaque del Norte, the top of the Miocene has a considerable sequence of limestones at least the bottom of which appear to be truly reefal.

Early Pliocene

The coral-rich silts and the occasional sands of the Río Cana continue to indicate deposition in shallow water and these are then followed by the thickest sequence of limestone seen in the region. Our knowledge of the environment of these beds is, unfortunately, incomplete. Though some levels may suggest reef framework, much would seem to be debris derived from the reef.

The Río Gurabo section shows a much greater increase in water depth at the base of the Pliocene than is seen in the Río Cana. A deep-water silt environment has only a small amount of allochthonous material being introduced at first, but, higher in the sequence, repeated influxes of terrigenous and shallow-marine debris are seen. A possible rise in sea level linked to a worldwide eustatic change is referred to in the section on the age of the Río Gurabo beds.

Little is known of the early Pliocene further east except for a number of outcrops along the Río Yaque del Norte that again suggest relatively deep water with the change taking place rather suddenly near the base of the Pliocene.

Middle Pliocene

Outcrops are, on the whole, sparse in this youngest interval seen. Sands and grits in the Cana and Gurabo sections could still have come downslope into deep water while, in the Río Mao, the type locality of the Mao Clay carries a deep-water foraminiferal fauna.

In the Río Gurabo occurs a pebbly limestone level that is younger than the thick limestones seen in the Río Cana. If the latter are considered to be Mao Adentro Limestone, it is difficult to place the Río Gurabo occurrence under the same name.

The Mao Adentro Limestone at its type locality (USGS locs. 8532, 8533 on Text-fig. 29) was described by T. W. Vaughan (Vaughan *et al.*, 1921, p. 73) as 21 m of conglomeratic limestone interbedded with bluish shale and underlain by 3.8 m of laminated sands and silts. The precise age of this horizon is not known by us.

The relation of these various limestones one to another has yet to be resolved.

The highest level seen in the whole area is the Tulane locality 1337 (Text-fig. 29) from the type locality of the Mao Clay on the Río Mao.

Our measured sections in the Río Cana and Río Gurabo represent, at most, a time span of five million years. This gives a maximum deposition rate of 24 cm/1000 years for the Río Cana and 18 cm/1000 years for the Río Gurabo. A considerable proportion of the time span is, however, probably represented by the many hiatuses associated with minor conglomerates as well as with several more major ones. Also, the overall accumulation rates do not show the considerable variations that occur within each section.

APPENDIX 1

THE USE OF FORMATION NAMES

The difficulty of applying formation names outside their immediate type areas will be apparent from the content of the present paper. However, for communication between workers a minimum of nomenclature is needed. For this reason, we here define those names that we use. They can only be considered as mappable units in the field in the broadest sense. Where no names are used as, for example, above the Baitoa Formation in the Río Yaque del Norte section, it is because we feel that to do so can only add confusion at this stage.

The definitions of terms follow those published in Hedberg (1976):

Lectostratotype: a stratotype selected later in the absence of an adequately designated original stratotype.

Hypostratotype: a stratotype designated to extend knowledge of the unit or boundary established by a stratotype to other geographical areas or to other facies. It is always subordinate to the holostratotype.

Baitoa Formation

Author.—C. W. Cooke, 1920.

Type locality.—Right bank cliff downstream from Baitoa on the Río Yaque del Norte. The difficulty of collecting from this near-vertical cliff face (Text-fig. 28) led Cooke to say that fossils could be found on the trail leading from Baitoa to Santiago, though the exposures are poor and fossils not abundant. The type locality is incorrectly placed too far downstream by Bold (1968, Text-fig. 6).

Hypostratotype.—Erected in the present work on the right bank of the Río Yaque del Norte below its confluence with the Río Bao and up- and downstream from the small gorge caused by the entry of the Arroyo Hondo (Text-fig. 21). As the type locality was clearly stated geographically, we do not take our section to be a lectostratotype and as it is about 400 m away from the original we consider it to be a hypostratotype in the sense given above. Photographic views of the section looking upstream and downstream are given on Plate 9.

Base of formation.—At the unconformable contact with the underlying Tabera Group (Represa Formation of Palmer, 1979) given as Horizon A on Text-figure 25.

Top of formation.—Not seen.

Thickness.—55 m were measured at the hypostratotype with a further 20 m (approximate) visible higher in the cliff. Northwards, towards the village of López, it is concealed below low ground.

Age.—On ostracode and molluscan evidence the age is taken as late early to early middle Miocene.

Cercado Formation

Author.—C. J. Maury, 1919. This was a new formational name replacing her *Aphera islacolonis* Formation (Maury, 1917b).

Type locality.—No single type locality was given. Instead, Maury included her Bluffs 2 and 3 on the Río Mao near Cercado, Zone G at Los Quemados on the Río Gurabo, and Zones I and H around Caimito on the Río Cana. The name indicates that she considered the Río Mao localities as constituting the type area. However, these outcrops are of limited vertical extent and show no contacts with formations above and below.

Lectostratotype on the Río Gurabo.—Both the Río Gurabo and the Río Cana possess relatively uninterrupted sections through beds originally designated as Cercado Formation by Maury. As the lectostratotype, we choose the section in the Río Gurabo because it has a clear top marked by the unconformity at the base of our designated Gurabo Formation, its lower part is more continuously exposed and more certainly measured, and it does not have the complication of the *Arca* beds that Maury later moved into her Caimito Formation.

Base of formation.—The unconformable contact of fossiliferous sands and pebble beds on the probable karstic surface of the Tabera limestones (Moncion Limestone of Palmer, 1979) at Monte Higuero.

Top of formation.—The unconformable overstep of the basal conglomerate of the Gurabo Formation at 145 m above the base of the stratigraphic column of Text-figure 6. This is approximately 4.25 km south of the old bridge at Los Quemados.

Thickness.—145 m.

Age.—Late Miocene, NN11 Zone, based on calcareous nannofossils.

Hypostratotype on the Río Cana.—We would take the bottom 275 m of the Río Cana section as Cercado Formation. This would include the section at Caimito listed by Maury (1917b, pp. 25, 26) and would include the *Arca* beds. This section she later designated as the Caimito Formation (Maury, 1931), but as there is some confusion about her actual meaning (see p. 10) and as the beds have not been found elsewhere, we do not continue to use the name.

Base of formation.—The unconformity with folded sandstones and shales of the Cordillera Central at the village of Cementerio.

Top of formation.—The base of a conglomerate (designated as the base of the Gurabo Formation for this section) at which level the lithology changes from pre-

dominantly silts and sands below to predominantly calcareous silts above.

Gurabo Formation

Author.—C. J. Maury, 1919. This was a new formational name replacing her *Sconsia laevigata* Formation (Maury, 1917b).

Type locality.—No single type locality was given. Instead, Maury included Zones F to A on the Río Gurabo around Los Quemados, and Bluff 1 on the Río Mao.

Lectostratotype.—We here designate the middle part of the Río Gurabo section, which includes within it Maury's Zones F to A, as the lectostratotype. It extends from a point approximately 4.25 km (measured in a straight line) upstream from the old bridge at Los Quemados, to a point 3.0 km downstream from the same bridge (see Text-figs. 4, 6).

Base of formation.—The unconformable base of a major conglomerate at 145 m on the stratigraphic column. This bed oversteps the Cercado Formation below.

Top of formation.—The erosional base of a series of channeled sands and conglomerates at 570 m on the stratigraphic column.

Thickness.—425 m.

Age.—Late Miocene and early Pliocene, NN11 to NN13 Zones, based on calcareous nannofossils, and ?*Globorotalia humerosa* Zone to *Globorotalia margaritae* Zone, based on planktic foraminifera.

Hypostratotype on the Río Cana.—We would take the base of the formation at the base of a conglomerate at 275 m above the base of the stratigraphic column of Text-figure 16. The top of the formation is taken at 575 m at the base of channeled sands and conglomerates overlying calcareous silts.

Mao Formation

Author.—P. J. Bermudez, 1949, p. 15. He included the Mao Adentro Limestone and Mao (=Valverde) Clay of Cooke (1920) together with "a thick section of silts, sands and conglomerates overlying these clays and limestones". He made two members, the lower comprising the Mao Adentro Limestone and, where limestone lenses are not present, clays and minor sandstones and limestones (presumably Cooke's Mao Clay). He gives the type locality of the Mao Adentro Limestone as being on the Río Gurabo, but this is incorrect, as it was described by Vaughan (*in* Vaughan *et al.,* 1921) from Mao Adentro on the Río Mao. The upper member of sandstones and conglomerates is said to have its type locality "on the lower course of Río Cana and Río Gurabo" (Bermudez, 1949, p. 15).

Hypostratotype on the Río Cana.—This seems to be one of the best reference sections for the formation.

Base of formation.—At 575 m on the stratigraphic column (Text-fig. 16) below a series of sands and conglomerates that overlie calcareous silts of the Gurabo Formation but underlie the limestone. This follows the concept of Bermudez (1949) who considered that such beds defined the base of the formation. In the Río Cana the Mao Adentro Limestone has been measured as 340 m thick. Above it, outcrops are nonexistent across low land that probably conceals Mao Clay. The section finishes in sands and conglomerates that must be those referred to by Bermudez (1949) as constituting his upper member.

Thickness.—From the base to the highest outcrop the thickness is thought to be 600 m though measurements are problematic between the highest outcrops.

Hypostratotype on the Río Gurabo.—The base of the formation is taken at 570 m on the stratigraphic column (Text-fig. 6), where channeled sands and conglomerates overlie calcareous silts. The section of 340 m between this point and the highest outcrops is difficult to subdivide, as a limestone mass equivalent to that seen in the Río Cana is not evident.

Age of formation.—In both Río Cana and Río Gurabo sections, the formation begins in the early Pliocene and continues into the middle Pliocene—that is, from approximately NN14 Zone to NN15 Zone or above, based on calcareous nannofossils and from the upper part of the *Globorotalia margaritae* Zone to the *Globorotalia miocenica* Zone, based on planktic foraminifera. The Mao Adentro Limestone in the Río Cana is considered to represent the upper part of the *Globorotalia margaritae* Zone.

The age of the type locality of the Mao Clay on the Río Mao is NN16 Zone, based on calcareous nannofossils, and *Globorotalia exilis* Subzone, based on planktic foraminifera.

APPENDIX 2

REGISTER OF NMB MICROFOSSIL COLLECTING LOCALITIES

(s = same spot; G = geochemical analysis; M = paleomagnetic analysis; T = thin-section analysis)

NMB locality number	JS [John B. Saunders] field number	Equivalent macrofossil localities	Other studies (see Introduction)	Lithology and faunal remarks
				Río Gurabo (1978 field season)
15929	3412	15803	G	hard massive silt with few whole molluscs and many fragments, some foraminifera
15930	3413		G M T	hard massive silt 1.8 m above 15929
15931	3414		G	hard massive silt 2.3 m above 15930
15932	3415		G	hard massive silt 2.6 m above 15931
15933	3416		G	hard massive silt 2.6 m above 15932
15934	3417	15804 s	G	hard silt with lenses and infilled borings of very fine sand packed with *Amphistegina,* small molluscs, and bryozoa
15935	3418	15805		hard silt weakly bedded, with molluscs mostly as small fragments forming part of the matrix, 2 m below 15934
15936	3419		G	hard massive silt rich in molluscs and foraminifera, poorly sorted, 1.8 m below 15935
15937	3420		G	hard silt with diverse fauna scattered throughout and concentrated in lenses and burrows
15938	3421		G	massive weathered silt rich in *Amphistegina* with molluscs and rotted corals
15939	3422		G	variable silt to silty sand, fauna as for 15938
15940	3423		G	massive silt rich in *Amphistegina,* molluscs, echinoid impression, rotted corals
15941	3424	15806 s	G	hard massive silt with diverse fauna scattered and in pockets
15942	3425		G	hard massive silt with common *Amphistegina* showing no orientation, coral fragments conspicuous, minute lignitic fragments common
15943	3426	15807	G M	hard silt with bedding suggested by orientation of *Amphistegina* and lignite fragments
15944	3427		G T	as for 15943
15945	3428		G	silt and very fine sand, as for 15943
15946	3429		G	as for 15945
15947	3430			hard silt very rich in *Amphistegina*
15948	3431			(a) silt and (b) coral debris bed 75 cm above (a)
15949	3432			silt
15950	3433			silt
15951	3434			silt
15952	3435			silt
15953	3436	15809		12–15 cm bed of harder silt packed with *Amphistegina*
15954	3437			fine sand with molluscs and *Amphistegina*
15955	3438			thin layer particularly rich in *Amphistegina*
15956	3439			4–5 cm dark organic silty clay immediately above 15955
15957	3440			fine sand immediately above 15956
15958	3441	15810		sandy silt with sparse fauna
15959	3442			2 cm weathered grey to olive-green clay
15960	3443	15811		cubical weathering sandy silt 1.4 m above 15959
15961	3444			silt
15962	3445	15812 s		5 cm (maximum) thick lens of shell debris, foraminifera, bryozoa, corals, traceable for 4 m
15963	3446	15813		silt
15964	3447	15814		10–15 cm shell bed
15965	3448	15815	G	hard lens traceable for 20–30 m of shells, shell fragments and corals
15966	3449	15816	G M	on strike with end of 15965; less hard and with fauna more scattered
15967	3450	15817	G	sandy silt; poor fauna but with scattered molluscs

APPENDIX 2

Continued

NMB locality number	JS [John B. Saunders] field number	Equivalent macrofossil localities	Other studies (see Introduction)		Lithology and faunal remarks
					Río Gurabo (1978 field season)
15968	3451		G		silt 4.5 m above 15967
15969	3452	15818	M	G	shelly silt passing down into poorly fossiliferous sands
15970	3453		G		better clay above 15969 separated by distinct bedding plane break
15971	3454	15819			17 cm sand in silt; contains silt balls up to 7 cm, shell debris, echinoid spines, etc.
15972	3455		G		silt
15973	3456		G		silt 3.5 m above 15972
15974	3457		G		hard silt
15975	3458	15820 (15974–15976)	G		about 1.8 m above 15975 in same silt
15976	3459		G		50 cm above 15975 in same silt
15977	3460		G		blocky silt, slightly weathered
15978	3461				as for 15977
15979	3462		G	M	silt with foraminifera visible
15980	3463		G		silt
15981	3464		G		blocky silt as before
15982	3465		G		silt with sparse molluscs; probable good microfauna
15983	3466		G		silt showing ellipsoidal weathering
15984	3467		G		silt probably good for microfauna
15985	3468		G		silt 4 m above 15984
15986	3469		G		uniform silt
15987	3470		G		as for 15986 but more weathered
15988	3471		G	T	uniform clayey silt
15989	3472		G		as for 15988
15990	3473		G		as for 15988 but slightly more micaceous and fissile
15991	3474		G		as for 15988 but slightly richer in fauna
15992	3475		T		poorly sorted silty sand with shell debris, *Amphistegina,* etc.
15993	3476		T		poorly sorted sand, less rich than 15992
15994	3477		G		poorly sorted sandy silt with shell debris, *Amphistegina,* etc.
15995	3478		G	M	clayey silt with mollusc fragments, etc.
15996	3479		T		coarse, badly sorted sand
15997	3480				pebbly sand with clayey silt clasts up to 7 cm from base of bed
15998	3481		G		clayey silt mass, 20 cm ovoid, from poorly sorted sand matrix
15999	3482		G		very poorly sorted medium to coarse sand near base of bed
16000	3483		T		poorly sorted medium sand higher in bed than 15999
16001	3484				clayey silt from top of a sand bed; lignitic fragments common and shell debris
16002	3485				clayey silt with scattered larger grains; lignitic fragments, etc., as for 16001
16003	3486				hand specimen of concretionary flame structure
16004	3487		T		sand associated with flame structure
16005	3488		T		fine to medium sand
16006	3489				very fine sand with infrequent burrows filled with coarser sand
16007	3490		G		clayey silt with mollusc debris and foraminifera
16008	3491		G		silty clay with lignite fragments and visible fauna
16009	3492				sandy clayey silt with scattered coarser grains; foraminifera and mollusc debris
16010	3493				clayey silt rich in small molluscs, shell debris and foraminifera
16011	3494				very poorly sorted pebbly sand
16012	3495				very poorly sorted coarse to medium sand
16013	3496				bedded sandy silt
16014	3497		T		pebbly sand with silt clasts and wood fragments
16015	3498		G		clayey silt with mollusc fragments and foraminifera concentrated in burrows
16016	3499				massive silt rich in molluscs, foraminifera and lignite fragments

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NMB locality number	JS [John B. Saunders] field number	Equivalent macrofossil localities	Other studies (see Introduction)		Lithology and faunal remarks
16017	3500		G		shattered clay with foraminifera and small *Pinna*
16018	3501		G		silty clay very rich in small molluscs (scaphopods) and foraminifera
16019	3502		G		slightly silty clay less rich in fossils than 16018
16020	3503		G		silty clay with molluscs as fragments and casts
16021	3504				as for 16020
16022	3505	15821			silt and silty clay with fauna mainly in sand pockets
16023	3506	15821			silty clay with more silty pockets; molluscs and foraminifera
16024	3507				uniform silty clay; foraminifera visible
16025	3508		T		very poorly sorted pebbly sand with worn *Amphistegina*
16026	3509		G		silt
16027	3510		G		silt 1.5 m above 16026
16028	3511		G		silt with discontinuous lenses of coral debris
16029	3512				20 cm thick clay
16030	3513		G	M	coral debris bed with some heads up to 30 cm
16031	3514		G		dark colored silt with foraminifera visible
16032	3515				lensing sand in the silts of 16031 and 16033
16033	3516		G		silt with foraminifera visible; 80 cm above 16031
16034	3517		G		silt with scattered molluscs and corals
16035	3518		G		silt less rich in macrofauna than 16034
16036	3519		G		silt as for 16034
16037	3520		G		silt as for 16034
16038	3521		G		silt as for 16034
16039	3522		G		near base of 3.8 m silt rich in foraminifera
16040	3523		G		top of silt of 16039
16041	3524	15826 s	G	M	30 cm thick clay with scattered pebbles
16042	3525				10–40 cm sand with pebbles up to 10 cm; coral debris
16043	3526		G		2.5 m bed of silt with scattered shells and coral fragments
16044	3527		G		40 cm bed of coral debris packed in silt matrix
16045	3528		G		1.2 m bed of silt
16046	3529				a) 50 cm sand with clay balls and pebbles passing laterally into b) silt
16047	3530				50 cm conglomerate with erosive base and transitional top
16048	3531		G	M	center of 2 m silt
16049	3532		G		more clayey top of 2 m silt of 16048
16050	3533	15825 s	G		40 cm coral debris bed
16051	3534		G		1.5 m silt with scattered molluscs and few coral fragments
16052	3535		G		50 cm coral debris bed as 16050
16053	3536	15824 s	G		50 cm lensing conglomerate and silt with molluscs and corals
16054	3537		G	M	near bottom of 2.7 m silt with pockets of small shells
16055	3538		G		near top of silt of 16054
16056	3539	15823	G		2 m silt separated from 16055 by a fault
16057	3540	15822 s	G		45 cm packed coral debris and molluscs in silt
16058	3541		G		1.6 m silt
16059	3542				30 cm lensing coral bed
16060	3543				10 cm shattered tectonized dark clay
16061	3544		G		from middle of 2.4 m silt
16062	3545		G		near bottom of 1.3 m silt
16063	3546				50 cm conglomerate
16064	3547		G		20 cm silty clay between conglomerates 16063 and 16065
16065	3548				thin sandy conglomerate
16066	3549				thin conglomerate rich in corals
16067	3550		G		4 m silt with minor lenses of corals; sample 1.5 m above conglomerate of 16066
16068	3551		G		top of 4 m silt immediately below sand/silt of 16069
16069	3552		G		finely interbedded sand and silt

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NMB locality number	JS [John B. Saunders] field number	Equivalent macrofossil localities	Other studies (see Introduction)	Lithology and faunal remarks
				Río Gurabo (1978 field season)
16070	3553		G	2.5 m silt; sample taken 2 m above 16069
16071	3554			near top of silt with sandy nodules
16072	3555			pockets of sand (sampled) in 40 cm silt with pebbles and corals
16073	3556			
16074	3557		G M	50 cm conglomerate with corals sampled at bottom (16073) and top (16075) with 10 cm slightly pebbly silt 20 cm above base (16074)
16075	3558			
16076	3559		G	3 m silt with pebble and shell pockets and irregular thin layers of corals sampled at top immediately below lensing pebble bed
16077	3560			in middle of 80 cm silty sand
16078	3561		G	1 m from top of 4.5 m uniform silt
16079	3562		G	1 m from base of 3 m clayey silt with shell fragments; sampled immediately below 2 cm undulating pebbly sand layer
16080	3563		G M	60 cm below top of silt 16079
16081	3564			thin conglomerate with corals; load structures at base
16082	3565		G	near base of 2.5 m silt rich in shell fragments; immediately above 16081
16083	3566		G	40 cm coral debris bed; possible correlation with 16050
16084	3567	15827	G	in middle of 1.4 m silt rich in foraminifera
16085	3568			30 cm coral debris bed; possible correlation with 16052
16086	3569		G	silt rich in foraminifera 2.5 m above bed 16085
16087	3570		G	silt approximately 7 m above 16086
16088	3571		G	silt approximately 2 m above 16087 and just below conglomerate with corals
16089	3572		G	silt 1.5 m below hard bed 16090
16090	3573		G	40 cm calcareous sandstone with harder and softer parts
16091	3574		G	silt 1 m above 16090
16092	3575			1.2 m highly fossiliferous hard silt with pockets of fine conglomerate
16093	3576		G	blocky silty clay 20 cm above top of 16092
16094	3577		G	shelly silt rich in foraminifera
16095	3578	15828	G	lens of coral fragments with nests of delicate terebratulid brachiopods
16096	3579			hard lens 9 cm (maximum) thickness 1.8 m above 16095
16097	3580		G	near base of more than 8 m silt rich in foraminifera
16098	3581		G	near top of silt 16097
16099	3582			thin bed of corals and shell debris packed in silt
16100	3583		G	at top of 1.2 m silt
16101	3584		G	hard coral-rich bed up to 30 cm
16102	3585		G	several meters of silt with isolated coral heads and lenses of coral debris; sampled 2 m above 16101
16103	3586		G	silt very rich in foraminifera 2.5 m above 16102
16104	3587	15829	G M	silt with scattered coral heads 1 m above 16103 and 2.25 m below a 15 cm coral rubble bed
16105	3588		G	silt with foraminifera and ostracodes visible 40 cm above 15 cm bed
16106	3589		G	silt with pockets of shell debris 5 m above 16105; very rich in foraminifera
16107	3590			variable thickness pebble bed with shell fragments and whole shells
16108	3591		G	silt 1.6 m above 16107
16109	3592		T	isolated outcrop of very hard conglomeratic shelly calcareous sandstone. Varied fauna of foraminifera, corals, echinoid spines, and molluscs
16110	3593		T	1.5 m cross-bedded conglomerate of well-rounded pebbles in a coarse sand matrix; sorting appears bimodal
16111	3594		T	pebbly sandy clay with grains of 0.1 to 2 cm in a clay matrix with shell fragments
16112	3595	15831 s	M	siltstone with bedding picked out by common lignite fragments; mollusc fragments and casts

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NMB locality number	JS [John B. Saun- ders] field number	Equivalent macro- fossil localities	Other studies (see Intro- duction)		Lithology and faunal remarks
16113	3596		T		pebbly sandy claystone with shell fragments
16114	3597		T		bedded poorly sorted sandstone with silt partings; lignite fragments
16115	3598				sandy silt
16116	3599		T		sandy clayey silt with lignite fragments
16117	3600	15832			clayey sandy silt with pebbles up to 1.75 cm; shell fragments and foraminifera; this is perhaps a transported mass
16118	3601				calcareous cemented sands and pebbly sand layers near 16117
16119	3602				silt from a series of cross-bedded silts, sands and conglomerates
16120	3603	15833	G		pebbly silt with molluscs and foraminifera from cross-bedded silts, sands, and conglomerates
16121	3604				interbedded silt and sand with fine lignitic material on partings
16122	3605		G		pebbly silt very rich in shells
16123	3606	15835	G		shelly silt
16124	3607	15836	G		silt with molluscs, corals, bryozoa, and foraminifera
16125	3608		G		interbedded softer and harder silt with rich coral debris in the latter
16126	3609		G	M	1.5 m below 16125 and also in the softer silts
16127	3610	15837	G		hard silt between cemented layers; 4 m below 16126
16128	3611		G		cemented layer with softer pockets 20 m laterally from 16127
16129	3612	15841	G		silt with coral debris
16130	3613	15840	G		silt with coral debris 2.5 m below 16129
16131	3614	15839 s	G		silt with coral debris 3 m below 16130
16132	3615		G		silt with coral debris 3.3 m below 16131
16133	3616		M		silt
16134	3617	15842	G		15 cm discontinuous concretionary siltstone 1.2 m below 16133
16135	3618	15843	G		sand rich in *Amphistegina*
16136	3619	15844	G		sandy silt with some harder layers; rich in *Amphistegina* and soritids
16137	3620	15846	G		taken over 1 m of hard silt rich in small coral debris
16138	3621		G		as for 16137 and 5 m below
16139	3622		G		sand
16140	3623		G		silt rich in miliolids; less corals than above and below
16141	3624		G		silt rich in corals including *Porites* and small *Siderastrea*
16142	3625		G		weathered silt with carbonaceous material (1 piece 30 cm); 2.3 m below 16141
16143	3626				silt with more varied corals including *Porites* and *Siderastrea*; 1.5 m below 16142
16144	3627	15853 s	G		silt below concretionary ledge; 2 m below 16143
16145	3628	15851 s	G		silt 1 m below 16144
16146	3629				soft and hard silt above ledge with 45 cm coral head in position of growth
16147	3630		G		silty sand 5 cm below 16146 and probably same horizon as 16140
16148	3631	15860	G		silt rich in foraminifera including large soritids and *Amphistegina*
16149	3632		G		3–4 cm layer of silt and clay with carbonaceous material and gypsum
16150	3633		G		base of a coral debris bed with foraminifera visible
16151	3634		G	M	silt as for 16148
16152	3635	15863	G		soft silt interbedded with hard; rich in macrofauna; 65 m on strike and 4.5 m below 16151
16153	3636		G		silt rich in molluscs and solitary corals; richer coral levels above
16154	3637	15864	G		silt 4.5 m below 16153 and less rich
16155	3638	15865	G		shelly silt rich in vermetids
16156	3639	15866 s	G		silt with molluscs including oysters, solitary corals and foraminifera
16157	3640	15867	G		silt with molluscs and foraminifera
16158	3641	15868	G		silt as for 16157; a 20 cm fine sand layer close by
16159	3642	15869	G		weathered sandy silt
16160	3643	15870 s	G		silt with molluscs and solitary corals

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NMB locality number	JS [John B. Saunders] field number	Equivalent macrofossil localities	Other studies (see Introduction)			Lithology and faunal remarks
						Río Gurabo (1978 field season)
16161	3644	15872	G			sandy silt with pockets of *Amphistegina*; solitary corals; sampled over 80 cm
16162	3645	15873	G	M		8–10 cm packed shells and *Amphistegina*; more scattered above
16163	3646		G			laminated top of sand bed passing down into 16164
16164	3647	15875	G			massive fine sand; solitary corals seen towards base
16165	3648	15876 s				silty fine sand with *Amphistegina, Oliva,* etc.
16166	3649		G			silty fine sand with *Amphistegina*
16167	3650	15878 s				shell bed, partly concretionary
16168	3651	15880	G			silty sand packed with *Amphistegina,* many in burrows
16169	3652	15881	G	M		cross-bedded sand with *Amphistegina*; rotted carbonaceous material
16170	3653		G	M		silt with *Callianassa*-size borings filled with shells and *Amphistegina*
16171	3654		G			silt with shell debris
16172	3655	15884	G			sandy silt with harder concretions, some containing algae
16173	3656	15886	G			sandy silt about equivalent to 16172
16174	3657					silt with harder lenses containing algae and corals
16175	3658	15888	G			silt with harder and softer parts; molluscs and solitary corals
16176	3659					bedded hard and soft silty sand
16177	3660		G			silt 75 cm below 16176; algae and solitary corals common
16178	3661		G			15 cm almost pure clay with distinct cleavage; 75 cm below 16177
16179	3662					conglomerate of metamorphic pebbles, algae, gastropods, corals; approximately 30 cm below 16178
16180	3663	15889	G			silt rich in macrofossils; infilled borings up to 1.5 cm diameter
16181	3664	15891				hard conglomerate from 1.8 m thick bed
16182	3665	15892				coral debris bed below conglomerate (16181); hard and softer pockets, algal balls
16183	3666					piece of Recent-looking wood from conglomerate
16184	3667		G			pebbly coral rubble bed
16185	3668	15893	G			silt with corals
16186	3669	15894	G	M		silt with solitary corals, molluscs and worn *Amphistegina* shells; approximately 1.5 m below 16185 and 10 cm below hard bed, on which the paleomagnetic analysis was performed; matrix noncalcareous in this sample and in the following sands.
16187	3670		G			very fine silty sand with mollusc fragments and *Amphistegina*
16188	3671		G	T		very fine sand; borings up to 4 cm diameter with 7 mm wall more clayey and better cemented with concentration of *Amphistegina* shells
16189	3672		G			40 cm interbedded silt and very fine sand; much lignite in silts; *Amphistegina* richer in sands
16190	3673	15899	G			clayey silt; molluscs, soritids and lignitic fragments common
16191	3674		G			silt richer than 16190; soritids up to 1.4 cm in diameter
16192	3675		G	M	T	silt, sandy in parts; cross-bedding picked out by pink *Amphistegina* shells and mollusc fragments; soritids present
16193	3676	15911				well-sorted very fine sand rich in molluscs, *Amphistegina* and soritids
16194	3677		G	T		very fine sand with shells scattered and in pockets; conglomeratic lenses
16195	3678	15912				fine sand packed with shells, shell fragments and foraminifera
16196	3679					hand specimen of bedded sand with coquina forming the top surface
16197	3680	15917				fine to medium cross-bedded sand; some small pebbles and shells
16198	3681		G			laminated silt to very fine sand; few shell fragments
16199	3682					conglomerate of well-rounded pebbles with mean size 1–2 cm, maximum 9.5 cm
16200	3683		G	M	T	very fine grained laminated sandstone with calcareous cement
16201	3684		G			poorly sorted pebbly sand

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NMB locality number	JS [John B. Saunders] field number	Equivalent macro-fossil localities	Other studies (see Introduction)	Lithology and faunal remarks
16202	3685		G T	poorly sorted, fine to medium grained, pebbly sand with wood fragments
16203	3686		M	calcareous sandstone
16204	3687	15919	G	silty sand very rich in whole and fragmented bivalves including *Anadara*
16205	3688	15920	G	shell bed rich in *Anadara*
16206	3689		G	variable lithology of sandy clay, silty clay and carbonaceous clay
16207	3690		G	silty clay and fine sand; carbonized wood layer 1 cm thick
16208	3691		T	medium to fine grained friable sand
16209	3692		G	claystone with lignitic silty clay interbeds
16210	3693		G T	friable sand with enclosures of lignitic clay and fragments of carbonized wood
16211	3694		M T	2–3 cm clayey silt with calcareous cement; pockets of fine to medium sand; very fine lignite–coal fragments
16212	3695		G T	calcified siltstone and shell coquina with impressions of plant leaves and common plant fragments
16213	3696	15922	G	shelly silty clay packed with mainly broken "*Modiola*" and other bivalves
16214	3697		G	silty claystone interbedded with lignitic silt; well-bedded to laminated
16215	3698	15923		angular to subrounded, fine to very fine sand; few shell fragments
16216	3699			siltstone with very fine sand partings; shell fragments
16217	3700	15924	M	concretionary sandstone rich in *Anadara*
16218	3701			medium grained sand with scattered pebbles; few shell fragments
16219	3702		M	dense limestone often with larger foraminifera visible
16220	3703		T	as for 16219
16221	3704		T	as for 16219
16222	3705		T	as for 16219
16223	3706		T	corals and algal balls loose on track; limestone fragments also sampled
16224	3707		T	dense limestone on hillside
16225	3708		M	concretionary sandstone with *Anadara*
16226	3709			20 cm long piece of grey clay in float
16227	3710			pieces of conglomerate and sandstone
16228	3711			lignitic and limonitic claystone; bedding picked out by plant fragments
16229	3712			clayey lignitic siltstone and bedded lignitic silty clays; 1 m above 16230
16230	3713			alternation of lighter colored claystone with darker, highly lignitic claystone
16231	3714			claystone with occasional large quartz grains; lignitic and coaly fragments
16232	3715			sandy conglomerate with pebbles up to 5 cm; some frosted quartz; lignitic specks
16233	3716			hard very poorly sorted conglomerate with well rounded dark igneous and chert pebbles up to 3 cm; partly recrystallized coral colonies embedded
16234	3717			corals from a coralliferous limestone
16235	3718		T	2 m red sandstone from below limestone
16236	3719		T G	3 m recrystallized algal limestone
16237	3720		T	very hard conglomeratic sandstone with shell beds, mainly *Anadara*
16238	3721		T	*Anadara* beds in sands with festoon bedding
16239	3722		T G	limestone with autobrecciated surface picked out by iron cement
16240	3723		T	algal limestone with pebbly silty pockets; all very hard
16241	3724			claystone with scattered larger grains and pockets of sand; lignitic, weathered
16242	3725		T	variable claystone to siltstone; occasional well-rounded frosted quartz grains
16243	3726		T G	limestone rich in larger foraminifera sampled with calcarenite 1 m below
16244	3727		T	calcarenite rich in small algal colonies and echinoid plates
16245	3728		T G	porcellanous limestone with algae, larger foraminifera and miliolids
16246	3729			limestone, as for 16245
16247	3730			piece of recrystallized coral colony from limestone
16248	3731		T	cemented boulder bed of coral colonies with some igneous pebbles
16249	3732		G	finer grained limestone of small fossil debris
16250	3733			recrystallized coral colonies and echinoid spines in limestone

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NMB locality number	JS [John B. Saunders] field number	Equivalent macro-fossil localities	Other studies (see Introduction)	Lithology and faunal remarks
Río Gurabo (1978 field season)				
16251	3734			conglomerate with large ?*Ostrea* and some corals
16252	3735		T	conglomerate with dark igneous cobbles up to 8 cm
16253	3736			shattered silty clay interbedded in conglomerate and sand
16254	3737		T	green schistose metamorphic rock
16255	3738			hard red-brown conglomeratic grit, very poorly sorted with flattened rounded pebbles up to 5 cm; black and green igneous components and algal colonies (? growing *in situ*)
Río Gurabito (1978 field season)				
16256	3739			dense algal limestone
16257	3740			dense limestone with larger foraminifera
16258	3741			foraminiferal calcarenite
16259	3742			siltstone with thin beds of very fine sand; wood–lignite fragments
16260	3743			coquina of mollusc debris in silty clay; some whole shells
16261	3744		T	dense limestone with algae and miliolids
16262	3745			slickensided silty lignitic clay
16263	3746		T	sandy pebbly silt; some frosted quartz
16264	3747			20 cm pebbly silty sand with *Anadara,* etc.; this is relatively unconsolidated
16265	3748		T	porcellanous limestone
16266	3749			pebbly calcarenite
16267	3750		T	conglomerate with interbedded sand lenses
16268	3751		G T	calcarenite below conglomerate
16269	3752		T	limestone with recrystallized coral heads up to 60 cm
16270	3753			pebbly sandstone associated with hard conglomerate
16271	3754		T	algal and shelly limestone
16272	3755			pebble bed plastered onto limestone surface
16273	3756			rather soft, very badly sorted conglomerate with rounded components up to 4 cm; mainly dark igneous rocks
Río Amina (1979 field season)				
16949	3889			sandy silt rich in *Amphistegina*; lenses and beds of *Amphistegina* and shells
16950	3890			as for 16949
16951	3891			as for 16949
16952	3892	16805		sandy clayey silt with solitary corals and some *Amphistegina*
16953	3893	16806		sandy silt with *Amphistegina,* solitary corals and some molluscs
16954	3894			as for 16953
16955	3895			as for 16953 but slightly more sandy
16956	3896	16807		clayey silt richer in foraminifera and with good solitary corals
16957	3897			silty clay rich in foraminifera
16958	3898			clayey silt with subconchoidal fracture
Río Cana (1979 field season)				
16959	3899			sandy silt with molluscs and foraminifera
16960	3900			as for 16959; rich in *Sphaerogypsina*
16961	3901			partly cemented silt rich in *Anodontia*
16962	3902	16858		concretionary siltstone
16963	3903	16860		silt packed with flat coral fragments (*Helioseris* or *Leptoseris*)
16964	3904	16862		sandy silt rich in coral debris and with molluscs
16965	3905			sand with concretions; softer parts sampled
16966	3906			silt with foraminifera visible

APPENDIX 2

Continued

NMB locality number	JS [John B. Saunders] field number	Equivalent macro-fossil localities	Other studies (see Introduction)	Lithology and faunal remarks
16967	3907	16817		silt rich in foraminifera including *Sphaerogypsina*
16968	3908			shelly sandy silt from between concretions
16969	3909			as for 16968; very rich in molluscs and *Sphaerogypsina*
16970	3910			as for 16969
16971	3911			as for 16969
16972	3912			as for 16969 with varied foraminiferal fauna visible
16973	3913	16824		from 8 m silt with concretions
16974	3914	16840		silt
16975	3915			silt with beds and lenses very rich in *Sphaerogypsina* and molluscs
16976	3916			from silt with layers of concretions
16977	3917	16829		silt with molluscs and foraminifera from below a well-burrowed bed
16978	3918			from 1 m silt with scattered pebbles
16979	3919			silt with carbonaceous material from within a pebble bed
16980	3920			1 m silt and sand with shells below a conglomerate and above a lignitic sandy clay
16981	3921			silt
16982	3922			carbonaceous silty clay
16983	3923	16835		shelly sand with pebbles up to 10 cm
16984	3924	16836		shell coquina from top of a silt
16985	3925	16819		shelly silt
16986	3926	16839		shelly silt overlying conglomerate with large *Arca*
16987	3927	16840		same bed as 16986
16988	3928	16843		sandy silt with scattered *Arca*; shells strongly concentrated at top of silt
16989	3929	16844		shelly silt rich in molluscs including scattered *Arca*
16990	3930			from 1 m silty clay with molluscs above an *Arca* bed
16991	3931			silt with scattered *Arca* from below *Arca* bed of 16990; silt passes down into lignitic silty clay with small-scale cross-bedding
16992	3932			jarositic lignitic silty clay below oyster/*Arca* bed
16993	3933	16852		shelly silt 50 cm above an *Arca* bed
16994	3934			carbonaceous clay with shell fragments below *Arca* bed of 16993
16995	3935			shelly fine sand with *Tellina* and scarce *Arca*
16996	3936			silty clay
16997	3937			silt with small and fragmented molluscs and ostracodes; 1.5 m below an *Arca* bed
16998	3938			carbonaceous clayey sands and silts sampled 1 m below an *Arca* bed
16999	3939			sandy clayey silt with shell fragments
17000	3940			sand with silt pockets, sand-filled borings and lignitic films
17001	3941			clay with molluscs from below lowest *Arca* bed of main cliff
17002	3942	16853		conglomerate with pebbles up to 15 cm and coral heads
17003	3943	16854 s		lens a few cm by 60 cm, rich in *Tellina* and other small molluscs
17004	3944	16856		lenses of molluscs, small corals and calcareous sponges in silty sand
17005	3945			shelly silt with lenses very rich in molluscs and large soritids
17006	3946			fine sand with molluscs and foraminifera
17007	3947			pockets of softer silt with foraminifera and rotted coral debris from between concretions
17008	3948	16865 (17008–17009)		silt with concretions including hardened burrows up to 5 cm in diameter
17009	3949			silt without concretions above 17008
17010	3950	16866		silty sand with molluscs; probably about 3 m below 17009
17011	3951	16868		silt probably about 5 m above 17008
17012	3952			bedded fine sands and thin silts
17013	3953			silty fine sand about 3 m above 17012
17014	3954			hard silts with clayey sands between; channeled base, pebbly sands above

APPENDIX 2

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NMB locality number	JS [John B. Saunders] field number	Equivalent macrofossil localities	Other studies (see Introduction)	Lithology and faunal remarks
				Río Cana (1979 field season)
17015	3955			clayey silt with spatangoid echinoid
17016	3956	16869		silt sampled between concretionary layers
17017	3957	16871		on strike with 17016
17018	3958			1 m sand with convoluted sand and silt balls—?thixotropic
17019	3959			gritty silt with foraminifera and poor molluscs above a 1 m conglomerate
17020	3960			silty sand below base of main limestone
17021	3961	16873		pocket of shelly pebbly sand within pebbly limestone 3.5 m above base
17022	3962			large clypeasteroid echinoid from limestone gorge
17023	3963			silt with scattered coral heads interbedded with harder coral debris layers
17024	3964	16885		shelly sand with *Conus*
17025	3965			pebbly clayey silt
17026	3966			50 cm carbonaceous clay, almost a lignite at base; 4 m above silt of 17005
17027	3967			clay passing down into lignite
17028	3968			shelly silt
17029	3969			carbonaceous clay
17030	3970			shelly silt 1 m below 17029
17031	3971			lignitic clay 50 cm below 17030
17032	3972			shelly silty sand equivalent to 17030
17033	3973			carbonaceous clay below 3 m pebbly sand
17034	3974			1.5 m silt below a carbonaceous silty clay
				Santiago–Baitoa road (1979 field season)
17158	4098			weathered silt with mollusc fragments and casts
17159	4099			weathered silt
17160	4100			as for 17159
				Río Yaque del Norte (1979 field season)
17161	4101		T	hard grit with *Lepidocyclina,* algal colonies, echinoid debris and corals
17162	4102			hard silty shale
17163	4103			shale and 10 cm grit with *Lepidocyclina*
17164	4104			hard silt
17165	4105			hard silt
17166	4106			compact clayey silt
17167	4107			hard silt
17168	4108			sandy silt half way up high cliff
17169	4109			as for 17168, about a quarter of way up high cliff
17170	4110			as for 17168, near base of high cliff at level of tree tops
				Río Bao (1979 field season)
17171	4111			above river and road; cliff of hard splintery silty shale with one or two hard concretionary layers per m
17172	4112			interbedded clayey silts with silts and pebbly sandstones; grading, shale slabs
17173	4113			as for 17172 and 35 m below
17174	4114			as for 17173 and 18 m below
				Río Mao (1979 field season)
17175	4115	16910		silts with scattered molluscs and foraminifera
17176	4116	16914		9 cm crushed clay with silt films
17177	4117	16924 s		partly cemented shell lens in silts

APPENDIX 2

Continued

NMB locality number	JS [John B. Saunders] field number	Equivalent macrofossil localities	Other studies (see Introduction)	Lithology and faunal remarks
17178	4118	16926 s		45 cm cross-bedded shell bed with soritids common
17179	4119			hand specimen of concretionary layer packed with *Amphistegina*
				Río Gurabo (1979 field season)
17180	4120			shell-filled burrows in sandy silt immediately below hard ledge of 15973
17181	4121			silt almost free of corals between grain-supported coral layers at 16137
17182	4122			40 cm lens of silt with scattered molluscs in coral bed at 16150
17183	4123	16934		relatively coral-free silt between large coral heads at macro locality 15855 (=16934)
				Río Yaque del Norte (1979 field season)
17184	4124			50 cm silt packed with small molluscs and soritids
17185	4125			concretionary shelly silt
17186	4126			small lens of highly lignitic sand
17187	4127			irregular concretionary shell beds
17188	4128	16938 (17188–17189)		soritids from shelly silt of 17189
17189	4129			silt with shells scattered and concentrated in burrows
17190	4130	16942		20 cm silt packed with '*Turritella*'
17191	4131			1 m long slumped silt ball out of pebbly sand matrix
17192	4132			limestone cobble from conglomerate 1.5 m below 17191
17193	4133			silty clay near base of 5.5 m of sands, silts and fine conglomerates immediately below unconformity and approximately 4 m stratigraphically above 17191
				Santiago–Baitoa Road (1979 field season)
17194	4134			blocky silty clay
17195	4135			blocky silty clay with squeezed clay partings
17196	4136			silty clay above river in Santiago
				Río Yaque del Norte (1980 field season)
17293	4190			blocky clayey silt with pteropods and planktic foraminifera; left bank in Santiago
17294	4191			silty sand rich in *Amphistegina,* coral debris and casts of molluscs interbedded with more indurated beds richer in corals
17295	4192			foraminiferal clayey silt
17296	4193			foraminiferal clayey silt with leaf impressions and *Dentalium* approximately 15 m above 17295
17297	4194			foraminiferal clayey silt 7–8 m above 17296
17298	4195	17266		uniform sandy silt
17299	4196			as for 17298
17300	4197			weathered silt with 5 cm layer of rotted corals
17301	4198			uniform sandy silt with foraminifera visible
17302	4199			as for 17301
17303	4200			as for 17301 and approximately 5 m above 17302
17304	4201			as for 17301 and approximately 5 m above 17303
17305	4202			sandy silt approximately 19 m above 17304 and 50 cm below a shell debris bed
17306	4203			silt with scattered shells approximately 6 m above 17305
				Río Mao (1980 field season)
17307	4204	17269		silty sand collected over a 1–2 m interval

APPENDIX 2

Continued

NMB locality number	JS [John B. Saunders] field number	Equivalent macrofossil localities	Other studies (see Introduction)	Lithology and faunal remarks
				Arroyo Zalaya (1980 field season)
17308	4205	17270		clayey silt with miliolids
17309	4206	17270		uniform clayey silt with scattered molluscs and lenses of shells and *Amphistegina*
17310	4207	17270		very uniform blocky clayey silt
17311	4208	17271		silt with thin conglomerate beds above
17312	4209	17271		uniform silt with foraminifera visible
17313	4210	17271		uniform blocky silt
17314	4211	17271		as for 17313, slightly weathered
				Río Yaque del Norte (1980 field season)
17315	4212			rather indurated bedded, sandy, and clayey siltstones in Santiago
17316	4213			low in 2 m silty clay interbedded with silty sand 60 cm above top of 2 m pebbly grit
17317	4214			clayey silt 2 m above top of fossiliferous rubble bed of macro locality 17274
17318	4215			pockets of clay at base of a coral reef limestone
17319	4216			silty clay below a coral rubble bed
17320	4217			1 m × 30 cm bedded silt clast in grit matrix
17321	4218			silty clay ball immediately below unconformity
17322	4219			concretionary rubbly silt rich in molluscs; softer parts sampled; miliolids visible
17323	4220	17287		burrowed sandy silt with shells and *Amphistegina*
17324	4221	17288		1 m × 30 cm lignitic sandy silt lens
17325	4222			burrowed silt with scattered molluscs and pebbles and lenses of *Turritella*; large oysters
17326	4223			strongly burrowed interval of 20 cm with *Amphistegina* and soritids
17327	4224			shelly silt with scattered pebbles; 90 cm above 17325
17328	4225			laminated siltstones interbedded with sands and fine conglomerates showing grading and load structures; shell fragments in coarser beds
				Río Bao (1980 field season)
17329	4226			clayey silt a few cm above marker clay bed

APPENDIX 3

REGISTER OF NMB MACROFOSSIL COLLECTING LOCALITIES

NMB locality number	PJ [Peter Jung] field number	Equivalent microfossil localities: same spot	Equivalent microfossil localities: same horizon	Mode of occurrence of fossils	Remarks
				Río Gurabo (1978 field season)	
15803	1429		15929	scattered in silts	collected thickness 2 m over a distance of 120 m
15804	1430	15934		in 15 cm thick sand	overlies 15803 directly; *Amphistegina* predominant; bulk sample (5 liters)
15805	1431		15935	scattered in silts	collected thickness 2 m over a distance of 80 m; bulk sample (5 liters)
15806	1432	15941		scattered in silts alternating with indurated layers	some corals
15807	1433		15942, 15943	scattered in indurated silts	corals and few molluscs
15808	1434			scattered in indurated 2 m thick bed full of coral rubble; base channeled	massive corals apparently in place, branching corals fragmented; coral deposit forms a flat lens up to 4 m thick and 100 m long; collected over the whole coral deposit (=16921)
15809	1435		15952, 15953, 15954	scattered in silts	some corals
15810	1436		15958	scattered in silts	collected thickness 1.5 m over a distance of 60 m
15811	1437		15960	scattered in silts	collected thickness 3–4 m; silt softer than at 15810; overlies 15810 directly
15812	1438	15962		in 5 cm thick sand	*Glycymeris* predominant
15813	1439		15963	scattered in silts	collected thickness 2 m over a distance of 150 m
15814	1440	15964		in 10–15 cm thick sand	bed 30 m long, then wedging out at both ends
15815	1441		15965	in up to 60 cm thick sand	bulk sample (5 liters)
15816	1442		15966	scattered in silts	above and below 15815; collected distance: 250 m
15817	1443		15967	scattered in silts	collected over a distance of 100 m
15818	1444		15969	scattered in silts	few molluscs; collected over a distance of 60 m
15819	1445		15971	scattered in silts	overlies 15818 directly; collected over a distance of 90 m
15820	1446		15974, 15975, 15976	scattered in silts	collected thickness 2 m over a distance of 40 m
15821	1447		16022, 16023	scattered in silts	few molluscs and corals
15822	1448	16057		60 cm thick bed of coral rubble overlying silts with undulating surface	mostly branching corals; few coral heads; in silty matrix of rubble bed some pteropods (*Diacria*)
15823	1449		16056	scattered in silts	underlies 15822 directly; pteropods (*Diacria, Cavolinia*), *Propeamussium* and other thin-shelled bivalves; bulk sample (5 liters)
15824	1450	16053		80 cm thick bed with coral rubble	
15825	1451	16050		70 cm thick rubble bed	corals and few molluscs (*Spondylus*); underlies 15824
15826	1452	16041		scattered in silts	collected thickness 1 m; some corals and few molluscs in upper part
15827	1453		16084	scattered in silts overlying 50 cm thick bed with coral rubble	pteropods and *Propeamussium*
15828	1454		16095	scattered in silts	pteropods, small solitary corals; terebratulid brachiopods predominant
15829	1455		16104	scattered in silts	pteropods; silts alternating with conglomerates and beds with coral rubble

APPENDIX 3

Continued

NMB locality number	PJ [Peter Jung] field number	Equivalent microfossil localities: same spot	Equivalent microfossil localities: same horizon	Mode of occurrence of fossils	Remarks
				Río Gurabo (1978 field season)	
15830	1456			large blocks of coral limestone	large oysters, *Plicatula*, boring bivalves, rare large echinoids
15831	1457	16112		scattered in 60 cm thick silt overlying 30 cm thick conglomerate	few molluscs; bedding planes full of plant debris
15832	1458		16117	scattered in sands with some pebbles (diameter up to 4 cm) underlying a conglomeratic layer	bulk sample (5 liters) for small fossils; collected over a distance of 70 m
15833	1459		16120	scattered in sands with pebbles (diameter up to 5 cm) underlying conglomerates	few corals; molluscs quite frequent; bulk sample (5 liters); collected over a distance of 80 m
15834	1460			in 15 to 20 m thick limestone	locality 15830 is stratigraphically equivalent; few corals
15835	1461	16123		scattered in silts	few molluscs; few bryozoans; *Amphistegina* predominant; bulk sample (5 liters) (=16812)
15836	1462		16124	scattered in silts	molluscs, corals and *Amphistegina*; collected thickness 1.5 m over a distance of 20 m; bulk sample (5 liters)
15837	1463		16127	alternation of silts with few corals and indurated layers full of corals partly in living position and few molluscs	
15838	1464			silts full of coral rubble and few molluscs	overlies 15837; solitary corals, branching corals, and coral heads
15839	1465	16131		silts full of coral rubble and few molluscs	collected thickness 7 m
15840	1466		16130	in 10 cm thick band full of vermetids	overlies 15839 directly
15841	1467		16129	coral rubble with few molluscs (mainly large cerithids)	collected thickness 4 m; overlies 15840 directly
15842	1468		16134	scattered in silts	collected over a distance of 50 m; bulk sample (5 liters)
15843	1469		16135	scattered in fine sands	collected over a distance of 30 m
15844	1470		16136	scattered in sands	molluscs and corals; collected over a distance of 50 m
15845	1471			silts with molluscs and corals	
15846	1472		16137, 16138	scattered in sands with indurated lenses of coral rubble; irregular surfaces; no bedding	collected over a distance of 70 m; bulk sample (10 liters)
15847	1473			scattered in silts with coral rubble	
15848	1474			scattered in silts with coral rubble	
15849	1475			silts with coral rubble	bulk sample (5 liters)
15850	1476			silts with coral rubble alternating with indurated layers	collected thickness 8 m (=16882)
15851	1477	16145		soft silts with coral rubble	situated within 15850; bulk sample (5 liters)
15852	1478			shells packed in 25 cm thick indurated layer	situated within 15850; overlies 15851 directly; bulk sample (5 liters)
15853	1479	16144		soft silts with coral rubble	situated within 15850; overlies 15852 directly; bulk sample (5 liters)
15854	1480			scattered in 60–80 cm thick bed of silts within coral rubble	bulk sample (5 liters) (=16811, 16883)
15855	1481			scattered in silts and coral rubble around huge, partly inverted coral heads	(=16934)
15856	1482			scattered in silts with coral rubble	

APPENDIX 3

Continued

NMB locality number	PJ [Peter Jung] field number	Equivalent microfossil localities		Mode of occurrence of fossils	Remarks
		same spot	same horizon		
15857	1483			scattered in silts with coral rubble alternating with indurated layers	
15858	1484			scattered in silts with coral rubble	stratigraphically under 15857; collected over a distance of 60 m
15859	1485			scattered in silts with coral rubble	collected over a distance of 20 m
15860	1486		16148	scattered in silts	few solitary corals; bulk sample (5 liters); collected over a distance of 20 m
15861	1487			scattered in silts with coral rubble	stratigraphically about 3 m above 15860
15862	1488			scattered in silts with coral rubble	collected over a distance of 50 m
15863	1489		16152	scattered in silts	collected over a distance of 50 m; few solitary corals; bulk sample (5 liters)
15864	1490		16154	scattered in somewhat indurated silts	solitary corals
15865	1491		16155	scattered in silts	solitary corals; collected over a distance of 40 m; bulk sample (10 liters) (=16810)
15866	1492	16156		scattered in silts	few corals
15867	1493		16157	scattered in silts	(=16808)
15868	1494		16158	scattered in silts	solitary corals; large *Spondylus*
15869	1495		16159	scattered in silts; occasional layers and lenses full of thin vermetids	solitary corals; bulk sample (5 liters)
15870	1496	16160		scattered in silts	solitary corals
15871	1497			scattered in silts	(=16809)
15872	1498		16161	scattered in silts	solitary corals; *Amusium*
15873	1499		16162	5 cm thick bed full of molluscs; silty matrix	*Oliva* predominant
15874	1500			10 cm thick silty bed full of molluscs	*Oliva* predominant; bulk sample (2 liters)
15875	1501		16164	scattered in silts	collected thickness 2 m; solitary corals; few molluscs; underlies 15874 directly
15876	1502	16165		silty band	bulk sample (2 liters)
15877	1503			scattered in silts	overlies 15876; solitary corals; few molluscs
15878	1504	16167		10 cm thick, silty bed full of molluscs	bulk sample (10 liters)
15879	1505			pectinids on surface of 20 cm thick, indurated layer	
15880	1506		16168	silts with band full of molluscs	*Oliva* predominant
15881	1507		16169	silts with thin band of molluscs	at one spot parallel specimens of *Dentalium*: current direction east–west or west–east; bulk sample (5 liters)
15882	1508			silts with burrows filled with small molluscs	bulk sample (2 liters)
15883	1509			scattered in silts	collected over a distance of 20 m
15884	1510		16172	few molluscs scattered in sandstone; sandstone with irregular, indurated layers	collected over a distance of 40 m
15885	1511			silts with irregular, indurated layers; numerous lucinids in living position	numerous specimens of *Turbo* and their isolated opercula; shell material leached; collected over a distance of 120 m
15886	1512		16173	scattered in silts with some indurated layers	corals; few molluscs; collected over a distance of 40 m
15887	1513			scattered in silts; few lucinids in living position	few corals; *Turbo* and their isolated opercula; shell material leached; collected over a distance of 60 m
15888	1514		16175	scattered in silts; lucinids in living position	few corals; *Turbo* and their isolated opercula; collected thickness 5 m over a distance of 80 m
15889	1515		16180	lucinids scattered in indurated silts	

APPENDIX 3
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NMB locality number	PJ [Peter Jung] field number	Equivalent microfossil localities: same spot	Equivalent microfossil localities: same horizon	Mode of occurrence of fossils	Remarks
				Río Gurabo (1978 field season)	
15890	1516			thin band with pectinids in silts	some calcareous lenses with pectinids and large foraminifera (diameter up to 3 cm)
15891	1517		16181	conglomerates with a few corals	
15892	1518		16182	coral rubble	underlies 15891 directly
15893	1519		16185	coral rubble with silty lenses	few badly preserved corals; large internal mould of a *Strombus*
15894	1520		16186	scattered in silts	solitary corals; underlies 15893; collected over a distance of 60 m
15895	1521			silts with thin band full of molluscs	collected over a distance of 40 m; bulk sample (5 liters)
15896	1522			silts with thin bands full of molluscs	bulk sample (5 liters)
15897	1523			silts with thin layers of molluscs	bulk sample (2 liters)
15898	1524			scattered in silts	collected over a distance of 70 m
15899	1525		16190	scattered in silts	few solitary corals; collected over a distance of 80 m
15900	1526			silts with bands full of molluscs	bulk sample (5 liters)
15901	1527			scattered in silts	
15902	1528			scattered in silts	overlies 15901
15903	1529			20 cm thick, silty band extremely rich in molluscs	bulk sample (60 liters)
15904	1530			several bands extremely rich in molluscs interbedded in silts	bulk sample (30 liters)
15905	1531			scattered molluscs and few solitary corals in silts	overlies 15904
15906	1532			silts with band full of molluscs	bulk sample (20 liters)
15907	1533			silty band full of molluscs	bulk sample (40 liters)
15908	1534			scattered in silts	collected over a distance of 50 m
15909	1535			scattered in silts	collected thickness 1 m over a distance of 300 m (=16920)
15910	1536			20–25 cm thick, silty band full of molluscs	bulk sample (20 liters)
15911	1537		16193	20 cm thick band full of molluscs in silts	bulk sample (20 liters); collected over a distance of 50 m
15912	1538		16195	conglomeratic shell bed; few *Oliva,* many fragile bivalves; pebbles with diameter up to 10 cm	bulk sample (20 liters)
15913	1539			conglomeratic shell bed	collected over a distance of 60 m
15914	1540			layer full of molluscs in silts	bulk sample (10 liters)
15915	1541			conglomeratic layer with molluscs in silts	bulk sample (10 liters)
15916	1542			15 cm thick, conglomeratic layer with molluscs in silts	bulk sample (2 liters)
15917	1543		16197	conglomeratic layer with molluscs	tellinids predominant; less venerids; few gastropods; collected over a distance of 30 m
15918	1544			scattered in silts	bivalves predominant; bulk sample (10 liters)
15919	1545		16204	20 cm thick shell bed in silts	*Anadara* predominant; lucinids, *Bulla, Melongena*
15920	1546		16205	scattered in silts; few concretions	*Anadara* predominant; collected thickness 1 m over a distance of 40 m; bulk sample (2 liters)
15921	1547			indurated silts full of molluscs	*Anadara* predominant; collected over a distance of 40 m
15922	1548		16213	10 cm thick, conglomeratic layer full of mytilids and some small *Melongena*	overlies 10 cm thick clay

APPENDIX 3

Continued

NMB locality number	PJ [Peter Jung] field number	Equivalent microfossil localities: same spot	Equivalent microfossil localities: same horizon	Mode of occurrence of fossils	Remarks
15923	1549		16215	sands, partly conglomeratic with few molluscs	*Anadara* and *Mytilus* predominant
15924	1550		16217	conglomeratic layer with fine sandy matrix	*Anadara, Mytilus* and *Melongena* predominant; collected over a distance of 50 m
15925	1551			few molluscs scattered in sands	*Anadara* and *Corbula* predominant; collected over a distance of 30 m
15926	1552			scattered in partly indurated silts	*Anadara, Melongena* and mytilids predominant; collected over a distance of 40 m
15927	1553		16264	shell bed in sands	*Anadara* predominant; collected over a distance of 15 m; Río Gurabito
15928	1554			corals in hard, silty matrix	Río Gurabito
				Río Mao (1979 field season)	
16801	1555			few fossils scattered in silts	collected thickness 2 m over a distance of 300 m
16802	1556			10 cm thick band with molluscs and *Amphistegina*	bulk sample (2 liters)
16803	1557			scattered in silts	numerous solitary corals and molluscs; includes short, thin lens with *Dentalium*; collected thickness 4 m over a distance of 100 m
				Río Amina (1979 field season)	
16804	1558		16950	scattered in silts	*Amphistegina* predominant; pectinids, *Amusium,* few corals; collected thickness 2 m over a distance of 200 m
16805	1559		16952	scattered in silts	solitary corals; few pectinids; collected over a distance of 50 m
16806	1560		16953	scattered in silts	Cañada de Mera; solitary corals; few *Amusium*; collected thickness 2 m over a distance of 200 m
16807	1561		16956	scattered in silts	solitary corals; few molluscs: *Cypraea*
				Río Gurabo (1979 field season)	
16808	1562		16157	gastropods and solitary corals scattered in silts	(=15867)
16809	1563			gastropods and solitary corals scattered in silts	(=15871)
16810	1564		16155	gastropods and solitary corals scattered in silts, but also concentrated in certain horizons	collected over a distance of 20 m and a thickness of 2 m (=15865)
16811	1565			coral rubble in silts concentrated in certain horizons; mostly solitary and platy corals	(=15854, 16883)
16812	1566	16123		scattered in silts	large oysters (=15835)
				Río Cana (1979 field season)	
16813	1567			alternation of silts and indurated beds relatively poor in fossils	Cañada de Zamba; frequent *Kuphus* perpendicular to bedding plane; collected thickness 2.5 m over a distance of 30 m
16814	1568			scattered in silts with some 5–10 cm thick, irregularly indurated lenses	Cañada de Zamba; overlies 16813 directly; collected thickness 1.5 m over a distance of 40 m

APPENDIX 3
Continued

NMB locality number	PJ [Peter Jung] field number	Equivalent microfossil localities: same spot	Equivalent microfossil localities: same horizon	Mode of occurrence of fossils	Remarks
				Río Cana (1979 field season)	
16815	1569			coral rubble in silty matrix; unclear bedding indicated by platy corals	Cañada de Zamba; collected thickness ca. 2 m from base of coral rock; platy and branching corals
16816	1570			partly indurated silts with *Kuphus*	Cañada de Zamba; collected over a distance of 30 m
16817	1571		16967	scattered in silts and concentrated in certain beds, not *in situ*; sediments appear to have slumped	Cañada de Zamba; *Anodontia,* lucinids, and strombids predominant; corals locally abundant; collected over a distance of 70 m; bulk sample (10 liters)
16818	1572		16968, 16969, 16970	scattered in silts but mainly concentrated within certain horizons, with indurated layers	Cañada de Zamba; large strombids, lucinids (not in living position), and turbinids predominant; corals: *Montastrea, Stylophora, Goniopora, Siderastraea,* burrows of ? crustaceans abundant; collected thickness ca. 4 m over a distance of 100 m; bulk sample (10 liters)
16819	1573		16985	scattered in silts with indurated layers	Cañada de Zamba; lucinids and turbinids predominant, mostly solitary corals; collected thickness 2 m over a distance of 100 m
16820	1574			1 m thick silty bed full of burrows; few molluscs	*Kuphus* frequent, not perpendicular to bedding plane
16821	1575			1.5 m thick silts with scattered molluscs	overlies 16820 directly; collected over a distance of 50 m
16822	1576			indurated beds in silts with hydrozoans (?); burrows	few corals (branching *Porites, Antillia*) and bivalves
16823	1577			1.5 m thick bed of coral rubble with partly recrystallized corals and hydrozoans	overlies 16822 directly
16824	1578		16973	molluscs and solitary corals scattered in silts, locally with burrows	collected thickness 1 m over a distance of 20 m
16825	1579			scattered in silts with indurated layers	overlies 16824 directly; collected thickness 2 m over a distance of 30 m
16826	1580			coral rubble (platy and branching corals); corals apparently *in situ*	collected from blocks; outcrop stratigraphically about 15 m above 16825
16827	1581			scattered in silts	corals; few molluscs
16828	1582			2.5 m thick silts with some indurated, thin layers full of molluscs and locally coral debris	*Gypsina* predominant; collected over a distance of 100 m; bulk sample (5 liters)
16829	1583		16977	silts with *Kuphus*	
16830	1584			silts with molluscs occurring in layers	*Kuphus* and *Astraea* predominant; large crab; collected thickness 1.5 m over a distance of 50 m
16831	1585			scattered in silts; lucinids partly in living position; *Kuphus* mostly perpendicular to bedding plane	frequent *Turbo,* their opercula isolated; collected thickness 1 m
16832	1586			50 cm thick bed with small molluscs	frequent *Astraea*; bulk sample (5 liters)
16833	1587			silts with small molluscs	frequent *Astraea* and *Tegula*; bulk sample (5 liters); collected thickness 1 m
16834	1588			silts with small lenses with molluscs	bulk sample (2 liters)

APPENDIX 3
Continued

NMB locality number	PJ [Peter Jung] field number	Equivalent microfossil localities: same spot	Equivalent microfossil localities: same horizon	Mode of occurrence of fossils	Remarks
16835	1589		16983	conglomeratic layers with pebbles of various sizes (maximum diameter 15 cm); pebbles irregularly scattered in sandy to silty matrix; fossils mostly concentrated in lenses	collected thickness 1.5 m over a distance of 20 m
16836	1590		16984	5 to 10 cm thick bed full of molluscs	bulk sample (5 liters)
16837	1591			silts with molluscs and bryozoans partly concentrated in layers	bulk sample (5 liters)
16838	1592			2 m thick silt with small pebbles and many scattered molluscs	overlies 1.5 m thick conglomerate (components with diameter up to 10 cm); bulk sample (20 liters); collected over a distance of 50 m
16839	1593		16986	1.5 m thick silts overlying 20 cm of conglomerates extremely rich in molluscs	*Pachycrommium* and other naticids predominant; collected over a distance of 30 m; bulk sample (25 liters)
16840	1594		16987	1.2 m thick silts with scattered molluscs especially in upper part	*Melongena, Anadara,* and large *Corbula* predominant
16841	1595			75 cm thick bed crowded with *Arca patricia*; matrix silty; specimens irregularly embedded; no preferred position, no orientation	underlies 16840 directly; other important faunal elements include *Melongena, Corbula, Mytilus, Anadara*; collected over a distance of 40 m
16842	1596			conglomeratic lenses with fossils	collected thickness 4 m over a distance of 50 m; bulk sample (2 liters)
16843	1597		16988	20 cm thick *Arca patricia* bed in silts	additional faunal elements: *Bulla, Melongena, Mytilus, Corbula*; collected over a distance of 70 m
16844	1598		16989	silts rich in scattered molluscs, few solitary corals and fragments of colonies	*Pachycrommium* predominant; collected thickness 1.9 m over a distance of 30 m; bulk sample (15 liters)
16845	1599			molluscs scattered in silts	*Corbula, Anadara, Melongena* predominant; collected thickness 70 cm over a distance of 20 m
16846	1600			20 cm thick *Arca patricia* bed resting on silts	collected over a distance of 20 m; underlies 16845 directly
16847	1601			35 cm of finely bedded silts with layers of *Mytilus,* some corals	
16848	1602			40–70 cm thick bed with *Arca patricia*; *Melongena,* fragments of *Mytilus,* few oysters	underlies 16847 directly; bulk sample (5 liters)
16849	1603			50 cm thick bed consisting almost exclusively of fragments of *Mytilus*	few *Melongena*; bulk sample (1 liter); separated from overlying 16848 by 20–25 cm thick bed of lignite
16850	1604			25 cm thick silty bed rich in *Arca patricia,* fewer *Melongena,* oysters, shell fragments	underlies 16849 directly
16851	1605			silty bed with large oysters and few *Arca patricia*	lateral equivalent of 16850; *Arca patricia* largely replaced by oysters
16852	1606		16993	scattered in silts	*Pachycrommium* predominant; collected over a distance of 60 m
16853	1607		17002	silts with scattered molluscs and corals	on upper surface of subjacent conglomerate bed: *in situ Solenastrea, Goniopora* and fragments of branching corals

APPENDIX 3
Continued

NMB locality number	PJ [Peter Jung] field number	Equivalent microfossil localities: same spot	Equivalent microfossil localities: same horizon	Mode of occurrence of fossils	Remarks
				Río Cana (1979 field season)	
16854	1608	17003		silts with a small lens full of molluscs	bulk sample (5 liters)
16855	1609			silts with concretions and small lenses of molluscs; large *in situ* coral head (*Montastrea*)	bulk sample (5 liters); collected over a distance of 80 m
16856	1610		17004	silts with a layer full of branching corals and molluscs	*Eurytellina* predominant; corals: poritids and *Stylophora*; bulk sample (10 liters); collected over a distance of 60 m
16857	1611			silts with some indurated layers containing large soritids, and lenses with molluscs and locally coral fragments	bulk sample (5 liters); collected over a distance of 130 m
16858	1612		16962	alternation of silts and indurated layers	large echinoid; crab claws; few coral fragments; red algae nodules; molluscs; collected thickness 2 m over a distance of 10 m
16859	1613			silts with concretions; corals predominant	collected over a distance of 40 m
16860	1614	16963		silts with indurated layers full of corals (*Pavona* sp.); probably *in situ*	
16861	1615			silts with indurated layers rich in corals	platy corals concordant to bedding plane, branching poritids fragmented
16862	1616		16964	silts with scattered solitary corals and molluscs	collected thickness 3 m over a distance of 60 m
16863	1617			hard silty beds full of corals	poritids dominant
16864	1618			stratified silts with scattered molluscs	
16865	1619		17008, 17009	silts with many indurated layers in lower part; scattered molluscs and corals; coral beds appear to have slumped	collected thickness 2 m over a distance of 140 m
16866	1620		17010	molluscs scattered in silts; very few *Thysanus*	collected thickness 2 m over a distance of 40 m
16867	1621			predominantly molluscs scattered in silts	overlies 16866; collected thickness 4 m over a distance of 20 m
16868	1622		17011	predominantly molluscs scattered in silts	overlies 16867; collected thickness 2 m over a distance of 20 m
16869	1623		17016	silts with scattered molluscs	collected thickness 4 m over a distance of 30 m
16870	1624			silts with few scattered molluscs	overlies 16869; collected thickness 5 m over a distance of 20 m
16871	1625		17017	silts with few scattered molluscs	overlies 16870; collected thickness 6 m over a distance of 20 m
16872	1626			sandy to pebbly silts with few scattered molluscs	collected thickness 3.5 m over a distance of 50 m; large burrows in upper 2 m
16873	1627		17021	pebbly sands with concretions; few corals, molluscs, and echinoids	collected thickness 4 m
16874	1628			limestone with coral colonies; not clear if in living position; skeletons badly altered	collected thickness 10 m over a distance of 80 m
16875	1629			limestone with corals and coral-inhabiting balanids; corals in living position; coral preservation poor	collected thickness 5 m over a distance of 5 m
16876	1630			limestone with corals and *Lithophaga*, coral preservation poor	collected thickness 12 m over a distance of 50 m
16877	1631			limestone with corals (*Millepora*) and few coral-inhabiting balanids	collected thickness 5 m over a distance of 20 m
16878	1632			silts with concretions	Cañada de Zamba; few *Spondylus* and *Kuphus*

APPENDIX 3
Continued

NMB locality number	PJ [Peter Jung] field number	Equivalent microfossil localities: same spot	Equivalent microfossil localities: same horizon	Mode of occurrence of fossils	Remarks
16879	1633			silts with layers rich in molluscs	Cañada de Zamba; collected over a distance of 40 m
16880	1634			silts with layers rich in molluscs	Cañada de Zamba; collected over a distance of 50 m
16881	1635			coral rubble; mainly platy corals; deposit apparently *in situ*; fragments of branching corals	Cañada de Zamba; collected thickness 2 m over a distance of 10 m
				Río Gurabo (1979 field season)	
16882	1636			silts with coral rubble alternating with indurated layers	(=15850)
16883	1637			scattered in 60–80 cm thick bed of silts within coral rubble	(=15854, 16811)
				Río Cana (1979 field season)	
16884	1638			limestone full of corals	few large oysters; brachiopods; collected thickness 3 m over a distance of 15 m
16885	1639		17024	stratified sands and silts with badly rounded pebbles (maximum diameter 8 cm); coral fragments and molluscs	*Limopsis* and *Natica* predominant; collected thickness 7 m
				Río Yaque del Norte (1979 field season)	
16908	1662		17161	conglomerates; corals and algae as components of conglomerate	collected thickness 3 m
16909	1663			silts with coral head	a single, derived specimen of a large land snail
				Río Mao (1979 field season)	
16910	1664		17175	silts with some indurated layers; fossils scattered	collected thickness 10 m over a distance of 150 m; bulk sample (5 liters)
16911	1665			limestone blocks with corals	blocks fallen from overlying Mao Limestone
16912	1666			scattered in silts	collected over a distance of 200 m; bulk sample (10 liters)
16913	1667		17307	silts with thin layers full of molluscs	bulk sample (30 liters) (=17269)
16914	1668		17176	scattered in silts; some layers full of molluscs and *Amphistegina*	collected over a distance of 140 m; bulk sample (5 liters) (=16931)
16915	1669			30 cm thick bed full of molluscs; silty matrix	bulk sample (10 liters); same horizon as 16927
16916	1670			scattered in silts	overlies 16915 directly
16917	1671			silts with 20 cm thick bed full of molluscs	bulk sample (5 liters) (=16923)
16918	1672			silts with 30–40 cm thick bed full of molluscs; partly cross-bedded	bulk sample (5 liters); stratigraphically about 2 m above 16917 (=16924)
16919	1673			scattered in silts	collected thickness 2.5 m over a distance of 70 m
				Río Gurabo (1979 field season)	
16920	1674			scattered in silts	(=15909)
16921	1675			scattered in indurated 2–4 m thick silty bed full of coral rubble; base channeled	massive corals apparently in place, branching corals fragmented; coral deposit forms a flat lens up to 4 m thick and 100 m long; collected over the whole coral deposit (=15808)

APPENDIX 3

Continued

NMB locality number	PJ [Peter Jung] field number	Equivalent microfossil localities		Mode of occurrence of fossils	Remarks
		same spot	same horizon		
				Río Mao (1979 field season)	
16922	1676			silts with 20 cm thick bed full of molluscs and *Amphistegina*	bulk sample (10 liters)
16923	1677			silts with 20 cm thick bed full of molluscs	bulk sample (20 liters) (=16917)
16924	1678	17177		silts with 30–40 cm thick bed full of molluscs; partly cross-bedded	bulk sample (20 liters) (=16918)
16925	1679			indurated silts full of molluscs	top part of bed of 16924
16926	1680	17178		silts with 30 cm thick bed full of molluscs	bulk sample (20 liters); same horizon as 16924
16927	1681			silts with 30 cm thick band full of molluscs	bulk sample (25 liters); same horizon as 16915
16298	1682			silts with 40 cm thick bed full of molluscs	bulk sample (20 liters); same horizon as 16924 and 16926
16929	1683			silts with 25 cm thick bed full of *Amphistegina*; few molluscs	tellinids predominant among molluscs; bulk sample (5 liters)
16930	1684			20 cm thick bed full of *Amphistegina*	bulk sample (5 liters)
16931	1685			scattered in silts	(=16914)
16932	1686			from two 5–10 cm thick and 1–2 m long lenses with molluscs	bulk sample (5 liters)
				Río Gurabo (1979 field season)	
16933	1687			lens of large coral heads in silty matrix; the whole coral material appears to have slumped; large corals not in place	maximum thickness of lens 3 m; lateral extension of lens 6 m; lens is embedded in material of 16934
16934	1688			scattered small molluscs and mostly branching corals in silts; corals fragmented; slumping	collected over a distance of 20 m and ca. 3 m of thickness (=15855)
				Río Yaque del Norte (1979 field season)	
16935	1689		17184	pebbly silty sands with scattered molluscs; also concentrated in horizons	collected thickness 4 m; some fossils rolled
16936	1690			1 m thick silts with scattered molluscs and corals	bulk sample (5 liters)
16937	1691			30 cm thick conglomeratic lens with abraded corals and molluscs	overlies 16936 directly
16938	1692		17188, 17189	3 m thick silts with scattered molluscs and few corals	overlies 16937 directly
16939	1693			20 cm thick conglomerate with abraded corals and few molluscs	corals, mostly *Siderastrea*
16940	1694			silts with scattered molluscs	collected thickness 1 m; overlies 16939 directly
16941	1695			scattered in silts	stratigraphically from above 16940; collected thickness 1.5 m
16942	1696		17190	20 cm thick silt full of *Turritella*	bulk sample (2 liters)
16943	1697			0.5 m thick conglomerate with rolled but well-preserved corals and few molluscs	corals probably not in living position; *Siderastrea, Coscinaraea, Stylophora*
16944	1698			0.5 m thick bed of *Montastrea, Siderastrea*; matrix sandy silts	many of the coral heads appear to be in living position
16945	1699			shelly conglomerate with some scattered molluscs and a few corals	

APPENDIX 3
Continued

NMB locality number	PJ [Peter Jung] field number	Equivalent microfossil localities: same spot	Equivalent microfossil localities: same horizon	Mode of occurrence of fossils	Remarks
				Rio Yaque del Norte (1980 field season)	
17265	1710			scattered in silts	same horizon as 16936
17266	1711		17298, 17299	silts with scattered molluscs and one solitary coral	collected thickness 4 m over a distance of 60 m
17267	1712		17302	scattered in silts, one fragment of *Stylophora*	collected thickness 15 m over a distance of 100 m
17268	1713			from 3 lenses full of fragile molluscs and solitary corals; maximum thickness of a lens 60 cm	
				Río Mao (1980 field season)	
17269	1714		17307	silts with thin layers full of molluscs	(=16913)
				Arroyo Zalaya (1980 field season)	
17270	1715		17308, 17309, 17310	silts with scattered molluscs	collected thickness 10–15 m over a distance of 1 km
17271	1716		17311, 17312, 17313, 17314	silts with few scattered molluscs	collected thickness 10–15 m over a distance of 800 m
				Río Yaque del Norte (1980 field season)	
17272	1717			concretionary sandstones with pebbles, broken corals, large *Spondylus,* large *Pecten, Anodontia, Plicatula*	collected thickness 2 m over a distance of 80 m
17273	1718			silts with scattered fossils; corals transported	collected thickness 2 m over a distance of 200 m; underlies 17272 directly
17274	1719			gritty rubble bed with coral heads, solitary corals, large oysters, pectinids, *Kuphus,* internal moulds of gastropods, and large echinoids	collected thickness 1.2 m over a distance of 130 m; underlies 17273 directly
17275	1720			silts with scattered molluscs and corals	collected thickness 3 m over a distance of 100 m; overlies 17272 directly
17276	1721			concretionary, well-bedded limestone with coral fragments and red algae nodules, burrows	collected thickness 3 m; overlies 17275 directly
17277	1722			2 m thick coral carpet; colonies *in situ*; few molluscs	collected over a distance of 50 m
17278	1723			silty sandstone (upper part concretionary) with scattered molluscs; shelly detritus	*Vasum* predominant; collected thickness 1.5 m over a distance of 70 m
17279	1724			rubble bed with clasts of marlstone and recrystallized broken corals	collected thickness 1.4 m
17280	1725			pebbly bed with scattered molluscs	
17281	1726			40 cm thick, conglomeratic lens with molluscs	
17282	1727			bed full of pebbles and molluscs	
17283	1728			conglomerate with small pebbles rich in molluscs; few corals	*Cymia, Phos, Conus* predominant
17284	1729			conglomerate with coarse pebbles, rolled and broken corals; some corals have grown on pebbles	mainly *Melongena, Vasum*; corals: *Coscinaraea, Siderastrea*

APPENDIX 3

Continued

NMB locality number	PJ [Peter Jung] field number	Equivalent microfossil localities: same spot	Equivalent microfossil localities: same horizon	Mode of occurrence of fossils	Remarks
				Río Yaque del Norte (1980 field season)	
17285	1730			concretionary siltstones with few scattered fossils	
17286	1731			sands and silts with scattered fossils and 2–3 layers with molluscs	collected thickness 3 m; bulk sample (5 liters)
17287	1732		17323	silts rich in molluscs	collected thickness 2.5 m; bulk sample (5 liters)
17288	1733		17324	scattered in silts	collected thickness 2.5 m
17289	1734			15–20 cm thick layer full of *Turritella*	bulk sample (5 liters)
17290	1735		17325, 17326, 17327	scattered in silts; includes 40 cm thick conglomeratic layer with molluscs	collected thickness 5 m

APPENDIX 4

REGISTER OF TU MACROFOSSIL COLLECTING LOCALITIES

(Information supplied by Dr. Emily Vokes. Asterisks indicate localities plotted on one or more of the Text-figures.)

TU 1205.—Roadcut at K 15–16, highway from Santiago to San Jose de las Matas, west of the bridge over Río Yaque del Norte at Santiago de los Caballeros.

TU 1206.—Roadcut at K 17, highway from Santiago to San Jose de las Matas, west of bridge over Río Yaque del Norte at Santiago de los Caballeros (=K 14 of Pflug, 1961).

TU 1207.—Roadcut at K 19, highway from Santiago to San Jose de las Matas, west of bridge over Río Yaque del Norte at Santiago de los Caballeros.

TU 1208.—Roadcut, both sides of highway from Mao to Los Quemados, at ridge 4 km east of Los Quemados.

TU 1209*.—Roadcut, both sides of the road, 2 km west of Los Quemados (and 0.6 km east of Río Gurabo) on road to Sabaneta.

TU 1210*.—Río Gurabo, east bank, first bluff downstream from ford on Los Quemados–Sabaneta road (=USGS 8544).

TU 1211*.—Río Gurabo, west bank, second bluff below the ford on Los Quemados–Sabaneta road (=USGS 8546).

TU 1212*.—Río Gurabo, east bank, third bluff below the ford on Los Quemados–Sabaneta road (=USGS 8548).

TU 1213*.—Río Gurabo, east bank, fourth bluff below the ford on Los Quemados–Sabaneta road (=USGS 8549).

TU 1214*.—Río Gurabo, fifth (=USGS 8550), sixth (=USGS 8551), seventh (=USGS 8552), and eighth (=USGS 8553) bluffs on both sides of river below ford on Los Quemados–Sabaneta road.

TU 1215*.—Río Gurabo, bluffs on both sides, from the ford on Los Quemados–Sabaneta road, upstream to approximately 1 km above the ford (=USGS 8539–8543; Maury's Zone D).

TU 1216*.—Roadcut at junction of road (south side of Río Yaque) from Santiago to Mao, with side road to "La Represa," 27 km west of bridge over Río Yaque del Norte at Santiago de los Caballeros.

TU 1217*.—Roadcut 1 km south of Potrero, or 5.5 km south of junction with road from Santiago de los Caballeros to Mao (south side of Río Yaque).

TU 1218*.—Río Amina, bluffs on east side below the dam "La Represa," 2 km south of Potrero.

TU 1219*.—Río Amina, bluffs on east side of river immediately upstream from ford that is 2 km west of Potrero and about 3 km downstream from "La Represa" (=USGS 8516).

TU 1220*.—Río Amina, bluffs on west side of river, about one-half km above the ford, which is 2 km west of Potrero, and about 3 km downstream from "La Represa" (=USGS 8517).

TU 1221.—Roadcut 4.5 km south of bridge at Guayubin, on road to Sabaneta.

TU 1222.—Roadcut 4.5 km north of plaza in Moncion, on road to Los Quemados.

TU 1223.—Roadcut 5.5 km north of plaza at Moncion, on road to Los Quemados.

TU 1224.—Roadcut 6.1 km west of Los Quemados, or 3.5 km west of Río Gurabo, on road to Sabaneta.

TU 1225*.—Banks of Arroyo La Sabirma on west side of the Río Mao, upstream from Mao Adentro and downstream from Cercado de Mao, about 11 km by (winding) road or 8 km airline, south of Mao.

TU 1226*.—East bank of the Río Yaque del Norte, below the village of Baitoa, and above the confluence of the Río Yaque and the Rio Bao (=USGS 8558, 8668).

TU 1227*.—Arroyo Zalaya, which crosses road to Jánico from Santiago de los Caballeros, 11 km south of bridge over Río Yaque del Norte at Santiago.

TU 1227A*.—Turbidity flow lens (ca. 30″ long, 6″ thick) about two feet above base of outcrop at point approximately 75 feet downstream from highway bridge.

TU 1228*.—Río Cana, west side, first bluff below the ford at Caimito on Los Quemados–Sabaneta road.

TU 1229*.—Río Cana, east side, bluffs about 1 km below the ford at Caimito on Los Quemados–Sabaneta road.

TU 1230*.—Río Cana, east bank, just above the ford at Caimito on Los Quemados–Sabaneta road (=USGS 8534; Maury's Zone H).

TU 1231.—Río Gurabo, float found in river gravel above and below ford on Los Quemados–Sabaneta road.

TU 1245.—Roadcut 5 km south of bridge at Guayubin, on road to Sabaneta.

TU 1246*.—Río Gurabo, both sides from 1 km to 2 km (airline) upstream from ford on Los Quemados–Sabaneta road (=USGS 8538; Maury's Zone E).

TU 1247.—Top of the bluff, east side Río Gurabo, at the horsetrail, which is about 2 km above the ford on Los Quemados–Sabaneta road.

TU 1248*.—Río Amina, first bluff downstream from ford at Potrero, on west side of river.

TU 1249.—Roadcut 8.6 km west of the plaza at San Cristobal, on road to Bani (=loc. H-20001 of Bermudez, 1949).

TU 1250*.—Río Verde, south bank, just above the ford at the crossing of a side road that connects Duarte Highway and La Vega–Moca Highway, about 10 km north of La Vega.

TU 1251*.—Río Verde, north bank, high bluff about 0.5 km down from the ford at the crossing of a side road that connects Duarte Highway and La Vega–Moca Highway, about 10 km north of La Vega.

TU 1252.—Arroyo Las Lavas, at crossing of Duarte Highway K 18.5 west of Santiago de los Caballeros on road to Navarette (=USGS 8663).

TU 1253.—Road cut on west side of road from Santiago de los Caballeros to Baitoa, 1 km north of the village of Baitoa (=USGS 8559).

TU 1254.—Roadcut at top of hill, 4 km west of Duarte Highway, on road to Presa Tabera; approximately 15 km south of Santiago de los Caballeros.

TU 1255.—Roadcut 13.9 km east of Río Yaque del Sur, at Quita Coraza, on road from Azua to Barahona (54.5 km east of Barahona).

TU 1256.—Roadcut 5 km south of Río Yásica, on old Puerto Plata–Santiago de los Caballeros highway (=loc. 15003 of Bold, 1968).

TU 1277*.—Río Gurabo, both sides, upstream from the horsetrail to 0.5 km above the trail, or approximately 2 km (airline) to 2.5 km above the ford on Los Quemados–Sabaneta road (=Maury's Zone F).

TU 1278*.—Large arroyo on east side of Río Gurabo just at the ford on Los Quemados–Sabaneta road.

TU 1279*.—Roadcut, south side of Los Quemados–Sabaneta road, 2.5 km west of Los Quemados and 0.3 km east of ford over the Río Gurabo.

TU 1280*.—Río Mao, bluff on west side about 1 km north of Cercado de Mao (=USGS 8733).

TU 1281.—Road metal quarry on highway, south side of Río Yaque, 1 km east of Guayubin on road to Mao.

TU 1282*.—Arroyo Beyaco, tributary of the Río Cana to the east, about 1 km above the ford at Caimito on Los Quemados–Sabaneta road (=Maury's Zone I).

TU 1283.—Río Yaque del Norte, south bank, just across from water purification plant at Santiago de los Caballeros.

TU 1284.—Río Yaque del Norte, south bank, at junction of road to San Jose de las Matas and road to Canela, 6 km west of Santiago de los Caballeros (? = USGS 8702, 8 km below Santiago).

TU 1292*.—Río Mao, west bank, bluffs about 1.5 or 2 km upstream from Mao Adentro, or about 9 km (by road) south of Mao (=USGS 8528).

TU 1293*.—Río Mao, west bank, bluff just below Paso Chorrera, or about 12 km (by road) south of Mao (=USGS 8519, 8520; Bluff 1 of Maury).

TU 1294*.—Río Mao, west bank, bluffs just above Paso de los Perros, about 5 km (by road) north of Moncion–San Jose de las Matas road (=USGS 8525; Bluff 3 of Maury).

TU 1295.—Road cuts in vicinity of junction of road to Naranjo with Moncion–San Jose de las Matas road, about 3 km east of the crossing of the Río Mao at Bulla.

TU 1296*.—Río Gurabo, both sides, from about 0.5 km above the horsetrail to approximately 1 km above the trail, or about 2.5 to 3 km (airline) above the ford on Los Quemados–Sabaneta road (=Maury's Zone F).

TU 1297*.—Río Gurabo, both sides, from about 1 km to 1.3 km above the horsetrail, or about 3 to 3.3 km (airline) above the ford on Los Quemados–Sabaneta road (=Maury's Zone G).

TU 1298*.—Río Gurabo, east bank at large eastward bend, about 1.5 km above the horsetrail, or 3.5 km (airline) above the ford on the Los Quemados–Sabaneta road (=USGS 8737).

TU 1299.—Roadcut, west side Los Quemados–Moncion road, 2 km south of Los Quemados.

TU 1300*.—Río Gurabo, west side, approximately 4 km by road (3.5 km airline) below the ford on Los Quemados–Sabaneta road (=USGS Bluff Q).

TU 1301*.—Río Cana, east bank about 2 km above the ford at Caimito on Los Quemados–Sabaneta road.

TU 1302.—Samba Hills Ridge; hill slope 2.5 km west of Guayubin (on south side of road, south side of Río Yaque).

TU 1303.—Roadcut, 3.5 km south of Guayubin, on road to Sabaneta.

TU 1304.—Roadcut, 4 km south of Guayubin, on road to Sabaneta.

TU 1305.—Oyster reef, unconformably on top of Cercado type sand, gully crossing Sabaneta–Guayubin road 15 km south of Guayubin.

TU 1306.—Fields beside road, 19 km south of Guayubin, on road to Sabaneta (*Arca patricia* Zone).

TU 1334.—Roadcuts, 2 and 2.3 km (same level) east of Martinez, which is about 9 km (airline) south of Mao.

TU 1335.—Roadcut, 5.6 km northeast of Martinez, or 1 km north of Entrada de Mao (approximately 9 km airline) southeast of Mao.

TU 1336*.—Río Mao, east bank just downstream from Paso Jiménez, or approximately 6 km (airline) south of Mao (=USGS 8532).

TU 1337*.—Barranca de Remolina, west bank Río Mao, approximately 3 km south of the plaza at Mao (=USGS 8530).

TU 1338*.—Roadcut, 0.3 km west of the ford over Río Gurabo, on the Los Quemados–Sabaneta road, or 2.9 km west of Los Quemados.

TU 1339.—Roadcut, 13.1 km south of bridge over Río Yaque del Norte at Santiago de los Caballeros, on the road to Jánico (9.4 km north of Jánico).

TU 1340.—Roadcut, 18.9 km south of bridge over Río Yaque del Norte, at Santiago de los Caballeros, on the road to Jánico (5.8 km north of Jánico).

TU 1341.—Roadcut, north side of highway, 6 km west of Sanchez, on Samana Highway (*Ostrea haitensis* reef).

TU 1342*.—Río Gurabo, east bank, approximately 4 km by road (3 km airline) below the ford on Los Quemados–Sabaneta road (=USGS 8554).

TU 1343*.—Río Gurabo, west bank, approximately 4.3 km by road (3.3 km airline) below the ford on Los Quemados–Sabaneta road (Bluff R of USGS).

TU 1344*.—Río Gurabo, west bank, approximately 5 km by road (3.5 km airline) below the ford on Los Quemados–Sabaneta road (=USGS 8735).

TU 1345*.—Río Gurabo, east bank, approximately 5.5 km by road (3.7 km airline) below the ford on Los Quemados–Sabaneta road (=loc. H15248 of Dohm and Bermudez; see Bold, 1968, p. 15).

TU 1346.—Road metal quarry on north side of road from Santiago de los Caballeros to San Jose de las Matas, about 1 km south of the bridge over Río Yaque del Norte, at Santiago.

TU 1352*.—Río Gurabo, east bank at first bluff above the ford that is approximately 1 km south of Gurabo Afuero.

TU 1353*.—Arroyo Puñal, outcrops on south side, above the crossing of the trail from Guayubal to Yabanal, which intersects the paved highway 1.5 km south of Guayubal (ca. 12 km airline southeast of Santiago de los Caballeros).

TU 1354*.—Cañada de Zamba, a tributary on the west side of the Río Cana, approximately 2.5 km east of the village of Zamba, which is 7 km north of Cruz de Santiago (Santiago Rodriguez), on road to Guayubin; or 4.5 km (airline) below the ford at Caimito.

TU 1355*.—Río Cana, west side, just below the mouth of Cañada de Zamba (see loc. TU 1354), which is 4.5 km (airline) below the ford at Caimito.

TU 1356*.—Río Cana, west side, just above the mouth of Cañada de Zamba (see loc. TU 1354), which is 4.5 km (airline) below the ford at Caimito.

TU 1357.—Río Yaque del Norte, bluff on west side, just above new (1980) water plant at south edge of Bella Vista, 3 km (by road) south of bridge at Santiago de los Caballeros.

TU 1358*.—Río Gurabo, west side, at and downstream from mouth of Arroyo La Cabra, approximately 6 km (airline) above the ford on Los Quemados–Sabaneta road.

TU 1359*.—Río Gurabo, east side, at long bluff that extends upstream from mouth of Arroyo Palero, approximately 5.5 km (airline) above the ford on Los Quemados–Sabaneta road.

TU 1360.—Roadcut, 0.5 km south of Las Caobas, on road to Los Ingenitos, which is on the west side of Río Gurabo.

TU 1361.—Roadcut, 3 km south of Las Caobas, on road to Los Ingenitos, which is on the west side of Río Gurabo.

TU 1362*.—Trail that leads to top of bluff, east side of Río Yaque del Norte, just downstream from Baitoa.

TU 1363*.—Boca de los Rios, above the waterfall in Arroyo Hondo, which enters Río Yaque del Norte from the east, just below the confluence with Río Bao, downstream from Baitoa.

TU 1364*.—Boca de los Ríos, below the waterfall in Arroyo Hondo, which enters Río Yaque del Norte from the east, just below the confluence with Río Bao, downstream from Baitoa.

TU 1365*.—Río Gurabo, west bank, approximately 4 km (airline) below the ford on Los Quemados–Sabaneta road.

TU 1366*.—Río Gurabo, west bank, approximately 4.5 km (airline) below the ford on Los Quemados–Sabaneta road (=loc. H15249 of Dohm and Bermudez; see Bold, 1968, p. 16).

TU 1367.—Roadcut 5.6 km west of fort at Mao, on road to Los Quemados.

TU 1368.—Roadcut, 0.5 km east of junction of road to Moncion at Los Quemados, on Los Quemados–Sabaneta road.

TU 1369*.—Roadcut at junction of road to new bridge and old road to the ford over Río Gurabo, 2.4 km west of Los Quemados, on Los Quemados–Sabaneta road.

TU 1370.—Río Guanajuma, a tributary of Río Amina from the west, bluffs on south side above the ford, which is approximately 1.5 km above the confluence with Río Amina.

TU 1371.—Río Guanajuma, a tributary of Río Amina from the west, bluffs on south side below the ford, which is approximately 1.5 km above the confluence with Río Amina.

TU 1372.—Roadcut, 2 km south of Las Caobas, on road to Los Ingenitos, which is on the west side of Río Gurabo.

TU 1373*.—Along trail at mouth of Arroyo Palero, west side Río Gurabo, approximately 5.5 km (airline) above the ford on Los Quemados–Sabaneta road.

TU 1374*.—Río Gurabo, east side, at long bluff approximately 0.5 km below the mouth of Arroyo Palero, or approximately 5 km (airline) above the ford on Los Quemados–Sabaneta road (? = USGS 8739).

TU 1375*.—Río Gurabo, west side, at long bluff approximately 0.5 km below the mouth of Arroyo Palero, or approximately 5 km (airline) above the ford on Los Quemados–Sabaneta road.

TU 1376*.—Río Gurabo, east side, about 0.25 km above mouth of Arroyo La Cabra, or approximately 6 km (airline) above the ford on Los Quemados–Sabaneta road.

TU 1377*.—Río Gurabo, west side, about 0.5 km above mouth of Arroyo La Cabra, or approximately 6.4 km (airline) above the ford on Los Quemados–Sabaneta road.

TU 1378*.—Río Gurabo, west side, at high bluff about 1 km above mouth of Arroyo La Cabra, or approximately 6.6 km (airline) above the ford on Los Quemados–Sabaneta road.

TU 1379*.—Río Mao, east bank, at mouth of Arroyo Bajon, just below Paso de los Perros, about 5 km (by road) north of Moncion–San Jose de las Matas road (across from Bluff 2 of Maury, and loc. USGS 8526).

TU 1380.—Roadcut at top of hill, 12.5 km south of traffic circle at Santiago de los Caballeros, on road to Baitoa.

TU 1381*.—Arroyo Babosico, bluffs just up from confluence with Río Yaque del Norte at La Barranca, approximately 8 km upstream from Santiago de los Caballeros.

TU 1382.—Roadcut, approximately 6 km west of Las Caobas, on Los Quemados–Sabaneta road.

TU 1403.—Arroyo Babosico, which enters Río Yaque del Norte from the west at La Barranca, approximately 8 km upstream from Santiago de los Caballeros, south side at first bluff below bridge on Las Charcas–La Barranca road.

TU 1404.—Arroyo Babosico, which enters Río Yaque del Norte from the west at La Barranca, approximately 8 km upstream from Santiago de los Caballeros, north side at second bluff below bridge on Las Charcas–La Barranca road.

TU 1405.—Arroyo Babosico, which enters Río Yaque del Norte from the west at La Barranca, approximately 8 km upstream from Santiago de los Caballeros, south side at fourth bluff below bridge on Las Charcas–La Barranca road.

TU 1406.—Roadcuts, Santiago–Jánico road, from 3 to 5 km west of junction with road to Baitoa, or 15 to 17 km northwest of bridge over Río Yaque del Norte at Santiago de los Caballeros.

TU 1407.—Roadcut, Santiago–Jánico road, 6.6 km west of junction with road to Baitoa, or 18.5 km northwest of bridge over Río Yaque del Norte at Santiago de los Caballeros.

TU 1408.—Roadcut, 1 km east of junction of road to Martinez and road to Mao, at Entrada de Mao, approximately 9 km (airline) south of Mao.

TU 1409.—Roadcut, 0.5 km west of junction of road to Martinez and road to Mao, at Entrada de Mao, approximately 9 km (airline) south of Mao.

TU 1410.—Río Mao, bluff on east side, 1 km upstream from Paso de Chorrera, or about half-way between Maury's Bluff 1 and Bluff 2 (=USGS 8521–8523).

TU 1411.—Río Guanajuma, which is a tributary of Río Amina from the west, bluff on north side just downstream from trail at Higuerito Penuelas, which goes to the river approximately 2.5 km upstream from the confluence with Río Amina; or about 1 km above

the ford on the road to Potrero.

TU 1412.—Río Guanajuma, which is a tributary of Río Amina from the west, bluff on south side just upstream from trail at Higuerito Penuelas, which goes to the river approximately 2.5 km upstream from the confluence with Río Amina; or about 1 km above the ford on the road to potrero.

TU 1413.—Río Gurabo, bluff on east side between the upper and lower fords at Gurabo Afuero, or about 0.5 km (airline) downstream from loc. TU 1352.

TU 1414.—Roadcut (new in 1981) on Mao–Los Quemados road, 2.2 km northeast of junction at Los Quemados.

TU 1415.—Roadcut (new in 1981) on Los Quemados–Sabaneta road, 1.8 km west of junction at Los Quemados, coral reef stratigraphically below level at locality TU 1209.

TU 1416.—Roadcut on new (rerouted in 1982) Los Quemados–Sabaneta road, 1 km east of Las Caobas.

TU 1417.—Río Gurabo, coral reef on east side of river, approximately 4.5 km (airline) above the ford on Los Quemados–Sabaneta road.

TU 1418.—Río Gurabo, shells from upper parts of conglomerate bed, west side of river, approximately 4 km above the ford on Los Quemados–Sabaneta road.

TU 1419.—Arroyo La Cabra, bluffs approximately 0.5 km upstream from its confluence with Río Gurabo, which is about 6 km (airline) above the ford on Los Quemados–Sabaneta road.

TU 1420.—Arroyo Bellaco (or Beyaco on topographic maps), which is a tributary of Río Cana from the east, first canyon above the ford at Las Caobas Adentro, 3 km southwest of Las Caobas.

TU 1421.—Arroyo Bellaco (or Beyaco on topographic maps), which is a tributary of Río Cana from the east, second canyon above the ford at Las Caobas Adentro, 3 km southwest of Las Caobas.

TU 1422.—Arroyo Bellaco (or Beyaco on topographic maps), which is a tributary of Río Cana from the east, coral reef that is exposed for approximately 1 km below the ford at Las Caobas Adentro, 3 km southwest of Las Caobas.

TU 1423.—La Isabela Fm., Type locality, 2 km southeast of site of La Isabela (original city), north coast, approximately 12 km due west of Luperon (see Marcano and Tavares, 1982).

TU 1434.—Roadcut 1 km east of the ford on Río Amina (see loc. TU 1219), at Potrero.

TU 1435.—Roadcut 1.5 km north of junction at El Limpio, on road from Piedra Gorda (which is 25 km west of Santiago and 24 km east of Mao, on south side of Río Yaque) to Cuesta Arriba.

TU 1436.—Roadcut 5 km north of junction at El Limpio on road from Piedra Gorda to Cuesta Arriba (see loc. TU 1435).

TU 1437.—Roadcut 0.5 km east of Los Caobas, on new (rerouted 1982) Los Quemados–Sabaneta road (approximately same place as loc. TU 1360, but about 20 m higher stratigraphically).

TU 1438.—Roadcut 0.5 km south of bridge at Guayubin, on road to Sabaneta.

TU 1439.—Roadcut 16 km south of traffic circle at Santiago de los Caballeros, on road to Baitoa.

TU 1440.—Río Gurabo, east bank, approximately 3.5 km (airline) below the ford on Los Quemados–Sabaneta road (=USGS 8556; Bluff U).

TU 1441.—Roadcut at top of hill at Noriega, which is 6.6 km (by road) south of Santiago de los Caballeros, on east side of Río Yaque (*Arca patricia* Zone).

TU 1442.—Roadcut just north of Arroyo Lopez, about 2.5 km west of Baitoa road and about 11 km (airline) south of Santiago de los Caballeros.

TU 1443.—Río Yaque del Norte, east bank, at López, just upstream from mouth of Arroyo López, between upper and middle hard limestone ledges.

TU 1444.—Río Yaque del Norte, east bank, at López, approximately 0.5 km upstream from mouth of Arroyo López, between middle and lower hard limestone ledges.

TU 1445.—Río Yaque del Norte, west bank, at "La Ventana" tunnel (López–Angostura hydroelectric project), between hard ledges just upstream from entrance to tunnel.

TU 1446.—Río Yaque del Norte, west bank, at "La Ventana" tunnel (López–Angostura hydroelectric project), hard ledges approximately 0.5 km downstream from entrance to tunnel.

TU 1447.—Access road to "La Ventana" tunnel (López–Angostura hydroelectric project), approximtely 0.5 km north of entrance to tunnel, on west side of Río Yaque, about 20 m above river level and locality TU 1446.

TU 1448.—Río Yaque del Norte, west side, bluffs extending for approximately 1 km upstream from the village of La Barranca.

TU 1449.—Río Yaque del Norte, west bank, large gravity flows exposed along road that leads down to river at village of La Barranca.

TU 1450.—Arroyo Dicayagua, a tributary of the Río Yaque del Norte, southwest of Santiago de los Caballeros, bluffs on both sides from bridge on highway to San Jose de las Matas, upstream for approximately 2 km.

TU 1451.—Arroyo Babosico, bluffs on both sides exposed upstream from the bridge at La Barranca to the junction with Arroyo Zalaya, about 1 km above the bridge.

TU 1452.—Arroyo Zalaya, bluffs on both sides exposed from crossing of the trail at village of Zalaya upstream for approximately 1 km.

TU 1453.—Arroyo Zalaya, from above the waterfall (which is approximately 1 km above the bridge on Santiago–Jánico road; see loc. TU 1227) to the headwaters.

TU 1453A.—Shallow-water gravity flows into the deep-water beds of Arroyo Zalaya, one just above waterfall, one about 0.5 km upstream (see loc. TU 1227A).

TU 1454.—Roadcut at top of hill (Loma La Furria), 7 km south of junction with Santiago–Jánico road at Las Charcas (or approximately 13 km south of Santiago), on López–Angostura hydroelectric project access road.

TU 1455.—Río Guanajuma, west side at large bend, approximately 1.5 km upstream (south) from trail at Higuerito Penuelas (see locs. TU 1411, 1412).

TU 1456.—Río Guanajuma, east side, long platform approximately 1 km upstream from trail at Higuerito Penuelas (see locs. TU 1411, 1412).

APPENDIX 5

REGISTER OF USGS MACROFOSSIL COLLECTING LOCALITIES

(from Vaughan *et al.*, 1921; includes only those localities cited in Appendices 2, 3, or 4, and (or) plotted on maps included with this publication; asterisks indicate localities plotted on maps)

USGS 8516*.—Province of Santiago, bluff on right bank Río Amina at ford near Potrero. T. W. Vaughan and C. W. Cooke, collectors. May 2, 1919.

USGS 8517*.—Province of Santiago, left bank of Río Amina about 0.5 km upstream from crossing at Potrero. T. W. Vaughan and C. W. Cooke, collectors. May 2, 1919.

USGS 8519*.—Province of Santiago, left bank of Río Mao about 0.8 km above the ford at Cercado de Mao; specimens mostly from lower part of bluff. T. W. Vaughan and C. W. Cooke, collectors. May 3, 1919.

USGS 8520*.—Province of Santiago, bluff on left bank Río Mao about 0.8 km above ford at Cercado de Mao; specimens from upper part of bluff. C. W. Cooke, collector. May 4, 1919.

USGS 8521*.—Province of Santiago, bluff on right bank of Río Mao about 1.7 km above Paso Bajito at Cercado de Mao; fossils from basal 4.5 m of section. T. W. Vaughan and C. W. Cooke, collectors. May 4, 1919.

USGS 8522*.—Province of Santiago, bluff on right bank of Río Mao, about 3 to 3.5 km above Cercado de Mao; fossils from 4.5 to 9 m above water. T. W. Vaughan and C. W. Cooke, collectors. May 4, 1919.

USGS 8523*.—Province of Santiago, bluff on right bank of Río Mao about 1.7 km above [Paso Bajito at] Cercado de Mao, 33 m above water level. C. W. Cooke, collector. May 4, 1919.

USGS 8524*.—Province of Santiago, bluff on right bank of Río Mao, about 3 to 3.5 km above Cercado de Mao. Loose, probably from between 8522 and 8523. T. W. Vaughan, collector. May 4, 1919.

USGS 8525*.—Province of Santiago, long bluff on left bank of Río Mao opposite Hato Viejo, about 5 km above the ford (Paso Bajito) at Cercado de Mao. T. W. Vaughan, C. W. Cooke, and D. D. Condit, collectors. May 5, 1919.

USGS 8526*.—Province of Santiago, second bluff on left side of Río Mao about 3.5 km by trail above the ford (Paso Bajito) at Cercado de Mao. T. W. Vaughan and C. W. Cooke, collectors. May 6, 1919.

USGS 8527*.—Province of Santiago, along the bluff on right bank Río Mao, opposite Cercado de Mao, first bluff below Paso Bajito. T. W. Vaughan and C. W. Cooke, collectors. May 6, 1919.

USGS 8528*.—Province of Santiago, long bluff on left side Río Mao at head of a long eastward reach about 3.5 km below Cercado de Mao, the second bluff on the left side below Paso Bajito. T. W.Vaughan and D. D. Condit, collectors. May 6, 1919.

USGS 8530*.—Province of Santiago, bluff on left side of Río Mao, about 3.4 km above intake of irrigation ditch at Valverde (Mao), first bluff above the town. C. W. Cooke, D. D. Condit, collectors. May 7, 1919.

USGS 8531*.—Province of Santiago, right bank of Río Mao, about 4.3 km above mouth of irrigation ditch at Valverde (Mao), first bluff on right bank above Valverde. C. W. Cooke and D. D. Condit, collectors. May 7, 1919.

USGS 8532*.—Province of Santiago, bluff on right bank of Río Mao, opposite Mao Adentro, from the coralliferous beds 4 to 24 m above the bottom of the exposure. T. W. Vaughan, collector. May 7, 1919.

USGS 8533*.—Province of Santiago, bluff on right side of Río Mao, opposite Mao Adentro, from lower part of the exposure. T. W. Vaughan, collector. May 7, 1919.

USGS 8534.—Province of Monte Cristi, bank of Río Cana at Caimito, road from Las Caobas to Sabaneta. T. W. Vaughan and C. W. Cooke, collectors. May 10, 1919.

USGS 8538*.—Province of Monte Cristi, left bank Río Gurabo about 1.6 km southeast of the upper ford at Gurabo Adentro, road from Las Caobas to Los Quemados, bluff 10 of traverse. T. W. Vaughan and C. W. Cooke, collectors. May 9, 1919.

USGS 8539*.—Province of Monte Cristi, left bank Río Gurabo about 1.3 km above upper ford at Gurabo Adentro, bluff 8 of traverse. T. W. Vaughan and C. W. Cooke, collectors. May 8, 1919.

USGS 8540*.—Province of Monte Cristi, right bank Río Gurabo about 0.4 km above upper ford at Gurabo Adentro, about 180 m downstream from station 8539, bluff 7 of traverse. T. W. Vaughan and C. W. Cooke, collectors. May 9, 1919.

USGS 8541*.—Province of Monte Cristi, right bank Río Gurabo, about 0.8 km above upper ford at Gurabo Adentro, bluff 6 of traverse. T. W. Vaughan and C. W. Cooke, collectors. May 9, 1919.

USGS 8542*.—Province of Monte Cristi, left bank Río Gurabo about 660 m above upper ford at Gurabo Adentro, bluff 5 of traverse. T. W. Vaughan and C. W. Cooke, collectors. May 9, 1919.

USGS 8543*.—Province of Monte Cristi, right bank Río Gurabo about 240 m above upper ford at Gurabo Adentro, bluff 4 of traverse. T. W. Vaughan and C. W. Cooke, collectors. May 9, 1919.

USGS 8544*.—Province of Monte Cristi, right bank of Río Gurabo, about 150 m above middle ford at Gurabo Adentro, bluff 3 of traverse. T. W. Vaughan and C. W. Cooke, collectors. May 9, 1919.

USGS 8545*.—Province of Monte Cristi, left bank of Río Gurabo, about 60 m downstream from middle ford at Gurabo Adentro, bluff 2 of traverse. T. W. Vaughan and C. W. Cooke, collectors. May 8, 1919.

USGS 8546*.—Province of Monte Cristi, left bank of Río Gurabo just above lower ford at Gurabo Adentro, bluff 1 of traverse. T. W. Vaughan and C. W. Cooke, collectors. May 9, 1919.

USGS 8548*.—Province of Monte Cristi, right bank of Río Gurabo, about 150 m below lower ford at Gurabo Adentro, bluff A of traverse. T. W. Vaughan and C. W. Cooke, collectors. May 8, 1919.

USGS 8549*.—Province of Monte Cristi, right bank of Río Gurabo about 0.4 km below the lower ford at Gurabo Adentro, bluff C of traverse. T. W. Vaughan and C. W. Cooke, collectors. May 8, 1919.

USGS 8550*.—Province of Monte Cristi, left bank of Río Gurabo, second bluff on left side below lower ford at Gurabo Adentro, bluff D of traverse. T. W. Vaughan and C. W. Cooke, collectors. May 8, 1919.

USGS 8551*.—Province of Monte Cristi, right bank of Río Gurabo, third bluff on right bank below lower ford at Gurabo Adentro, bluff E of traverse. T. W. Vaughan and C. W. Cooke, collectors. May 8, 1919.

USGS 8552*.—Province of Monte Cristi, left bank of Río Gurabo, about 0.8 km below lower ford at Gurabo Adentro, bluff F of traverse. T. W. Vaughan and C. W. Cooke, collectors. May 8, 1919.

USGS 8553*.—Province of Monte Cristi, right bank of Río Gurabo, about 180 m downstream from collection 8552, bluff G of traverse. T. W. Vaughan and C. W. Cooke, collectors. May 8, 1919.

USGS 8554*.—Province of Monte Cristi, right bank of Río Gurabo, about 2 km due north of lower ford at Gurabo Adentro, bluff P of traverse. T. W. Vaughan and C. W. Cooke, collectors. May 8, 1919.

USGS 8555*.—Province of Monte Cristi, right bank of Río Gu-

rabo, about 0.4 km northwest of bluff G, station 8553, bluff S of traverse. T. W. Vaughan and C. W. Cooke, Collectors. May 8, 1919.

USGS 8556*.—Province of Monte Cristi, right bank of Río Gurabo, about 3 km north of the lower ford at Gurabo Adentro, bluff U of traverse. T. W. Vaughan and C. W. Cooke, collectors. May 8, 1919.

USGS 8558*.—Province of Santiago, fossils fallen from upper part of bluff on right bank of Río Yaque del Norte below Baitoa. C. W. Cooke, collector. May 14, 1919.

USGS 8559.—Province of Santiago, roadside at top of hill leading down to Baitoa on road from Santiago. C. W. Cooke, collector. May 15, 1919.

USGS 8663.—Province of Santiago, Arroyo las Lavas, crossing of road from Santiago to Monte Cristi. T. W. Vaughan and C. W. Cooke, collectors. April 23, 29, 1919.

USGS 8668*.—Province of Santiago, Baitoa, bluff of yellow sandstone along Río Yaque del Norte. D. D. Condit, collector. April 19, 1919.

USGS 8702.—Province of Santiago, bluff on south bank of Río Yaque del Norte, 8.6 km west of Santiago. D. D. Condit, collector. April 20, 1919.

USGS 8733*.—Province of Santiago, bluff along west side of Río Mao, 1.7 km northwest of Paso Bajito, near Cercado de Mao. D. D. Condit, collector. May 6, 1919.

USGS 8735*.—Province of Monte Cristi, left bank of Río Gurabo, about 3.4 km below Gurabo Adentro, bluff W of traverse near base of cliff. D. D. Condit, collector. May 8, 1919.

USGS 8737*.—Province of Monte Cristi, Rio Gurabo, about 5 miles above Gurabo Adentro; base of coralliferous limestone and above conglomerate. D. D. Condit, collector. May 9, 1919.

USGS 8738*.—Province of Monte Cristi, Río Gurabo, about 8.5 km above Gurabo Adentro; beds near base of coralliferous limestone and above conglomerate. D. D. Condit, collector. May 9, 1919.

USGS 8739*.—Province of Monte Cristi, about 9.5 km up Río Gurabo from Gurabo Adentro; fossils from below conglomerate. D. D. Condit, collector. May 9, 1919.

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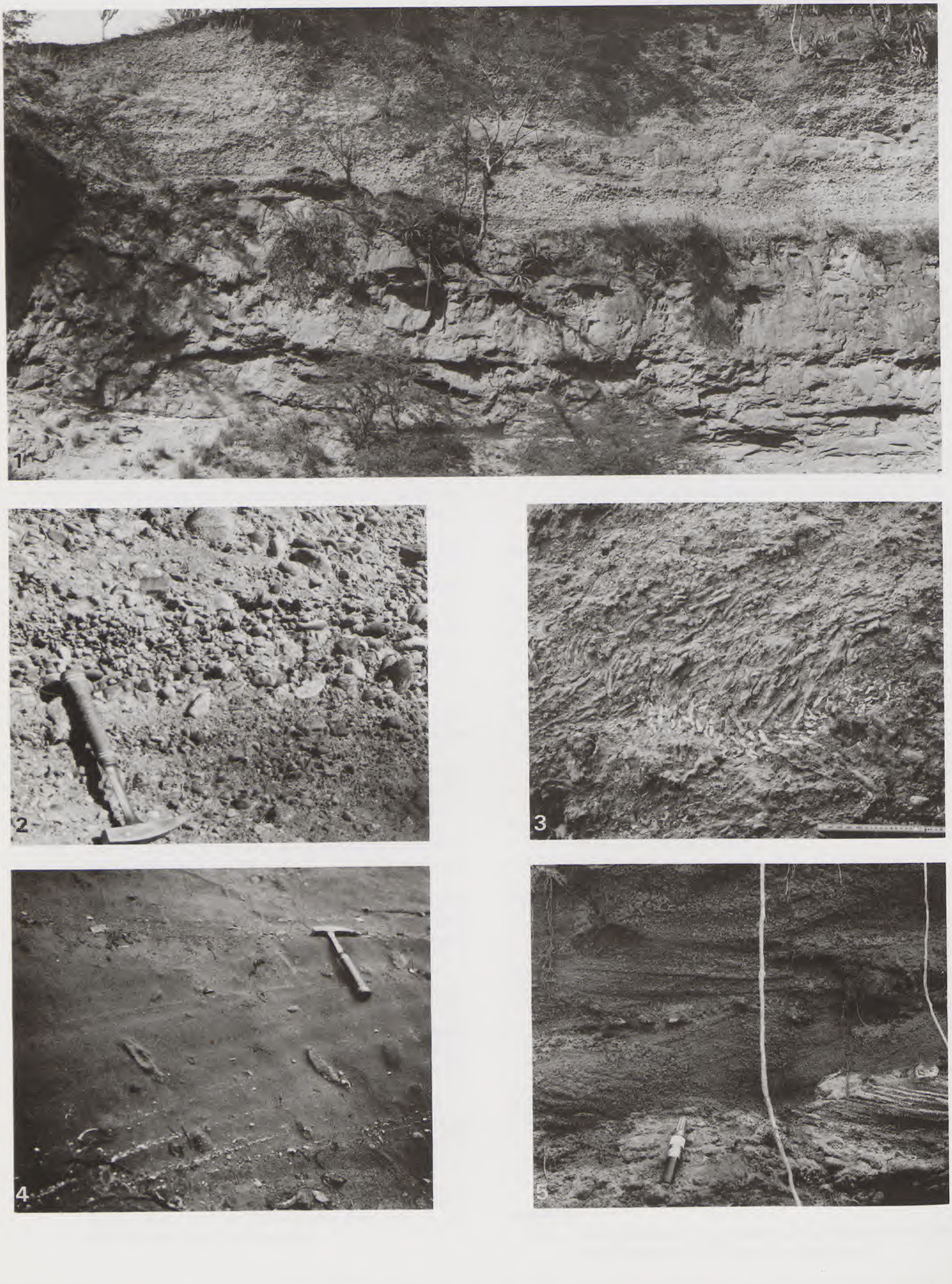
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EXPLANATION OF PLATE 1

Río Gurabo

The Cercado Formation, and the contact between Cercado Formation and the Gurabo Formation.

Figure Page

1. The basal conglomerate of the Gurabo Formation overlies sands and silty sands of the Cercado Formation. On this right bank cliff close to locality 15910, conglomerate lies directly on sands, having cut across the intervening coral debris bed. This situation is illustrated in the right hand sketch of Text-figure 9 .... 12, 13, 15
2. The basal conglomerate of the Gurabo Formation at NMB locality 16182. The well-rounded, poorly sorted nature of the pebbles and cobbles is apparent. At this locality, the conglomerate is only 2 m thick (see left hand sketch of Text-fig. 9)........ 12, 13, 15
3. Coral bed at the top of the Cercado Formation at NMB locality 16184. It shows a thicket of branching colonies (?a poritid) still in place, but distorted due to compaction and possible slight lateral movement. The individual coral fragments are still in contact at their points of breakage 11, 12, 15
4. Sand of the upper part of the Cercado Formation at NMB locality 16188. Bedding is picked out by small molluscs and by countless pink shells of *Amphistegina* that appear as white threads in the photograph 11,12, 15
5. Cross-bedded, coarse-grained, pebbly sand near the base of the Cercado Formation at NMB locality 16206. Thin conglomerates and lignites are also common at this level; examples of these can be seen in Text-figure 8........ 11, 15

EXPLANATION OF PLATE 2

RÍO GURABO

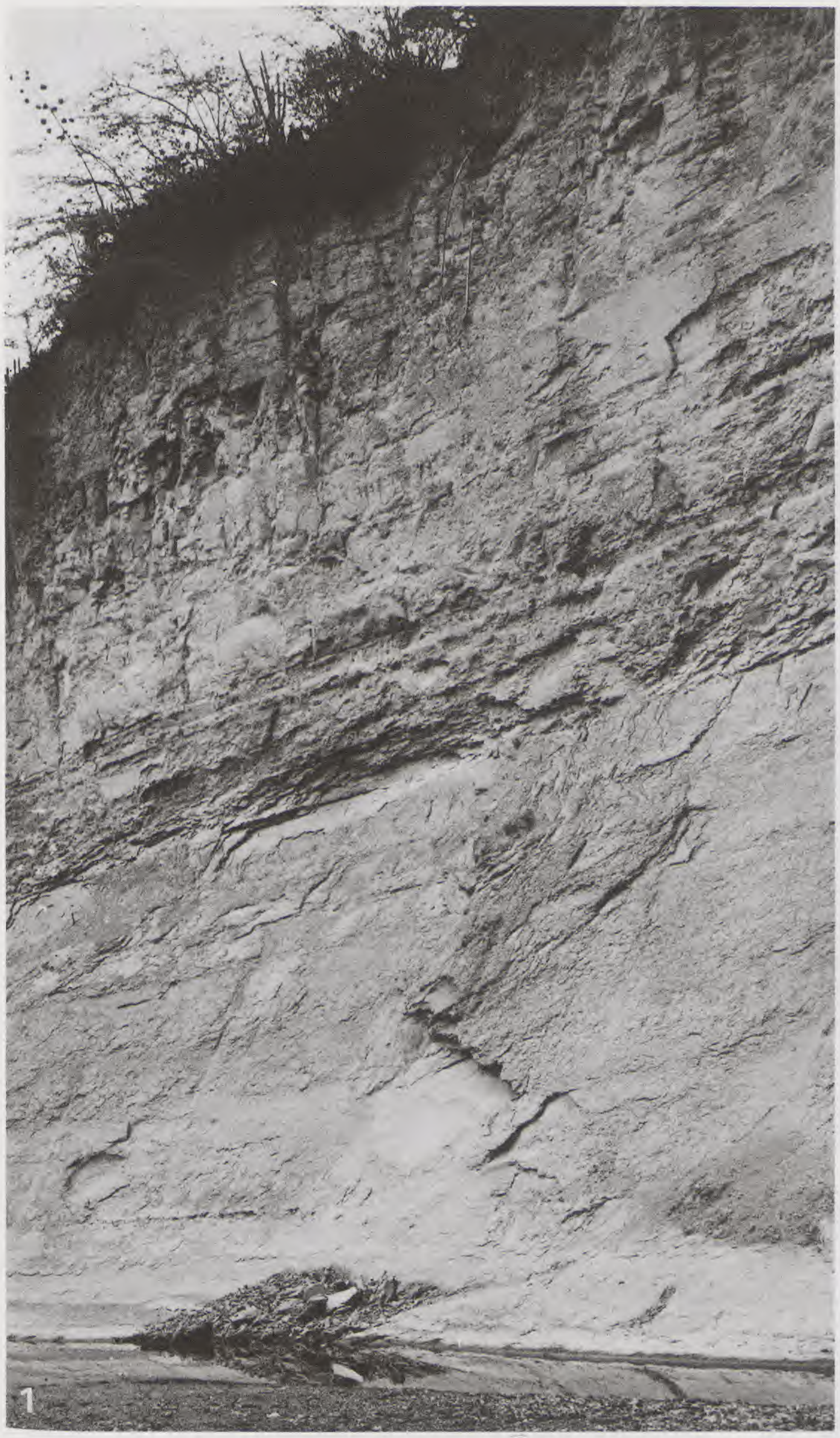
Gurabo Formation (comments on the corals by Dr. J. Geister)

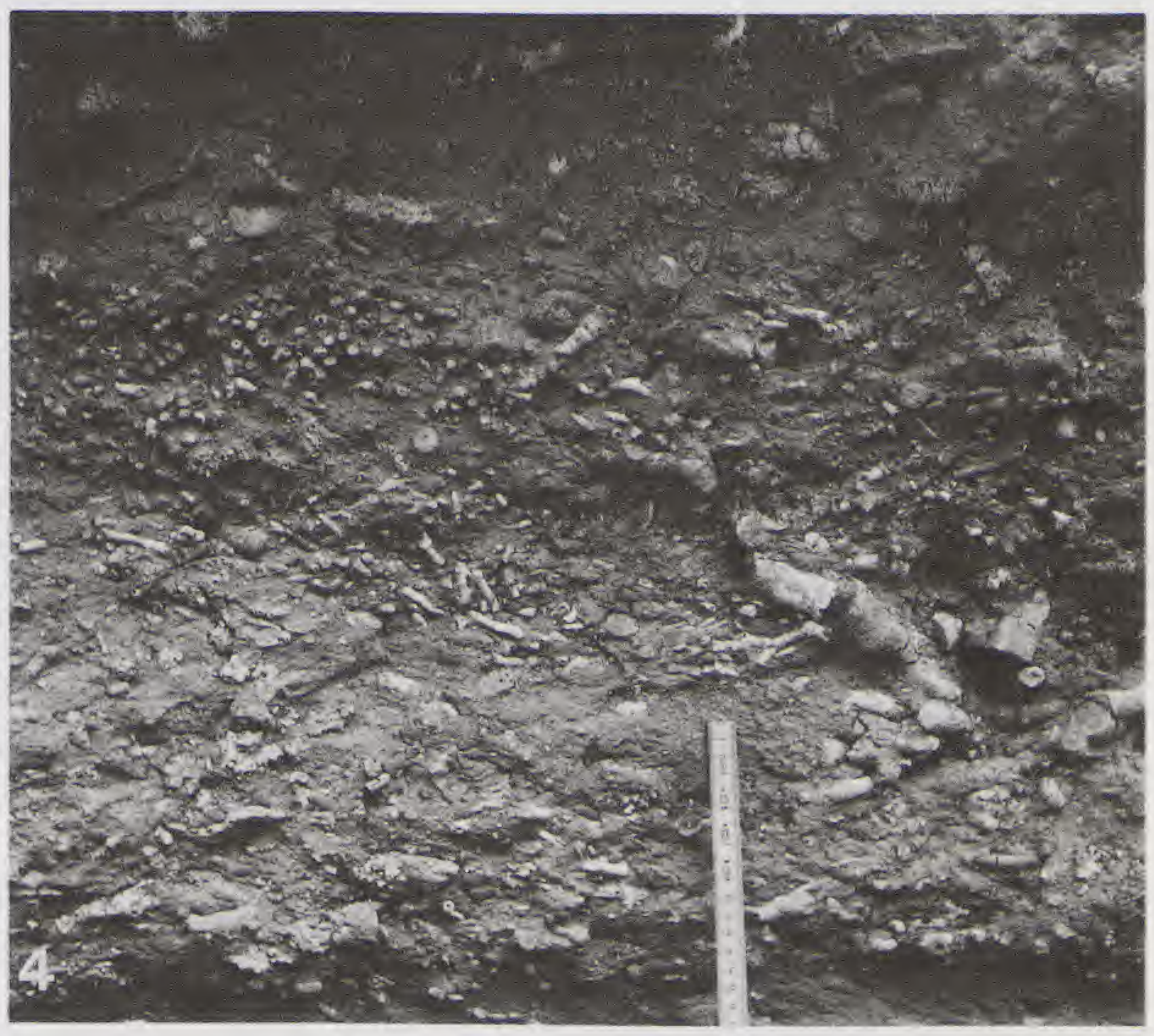
Figure | Page

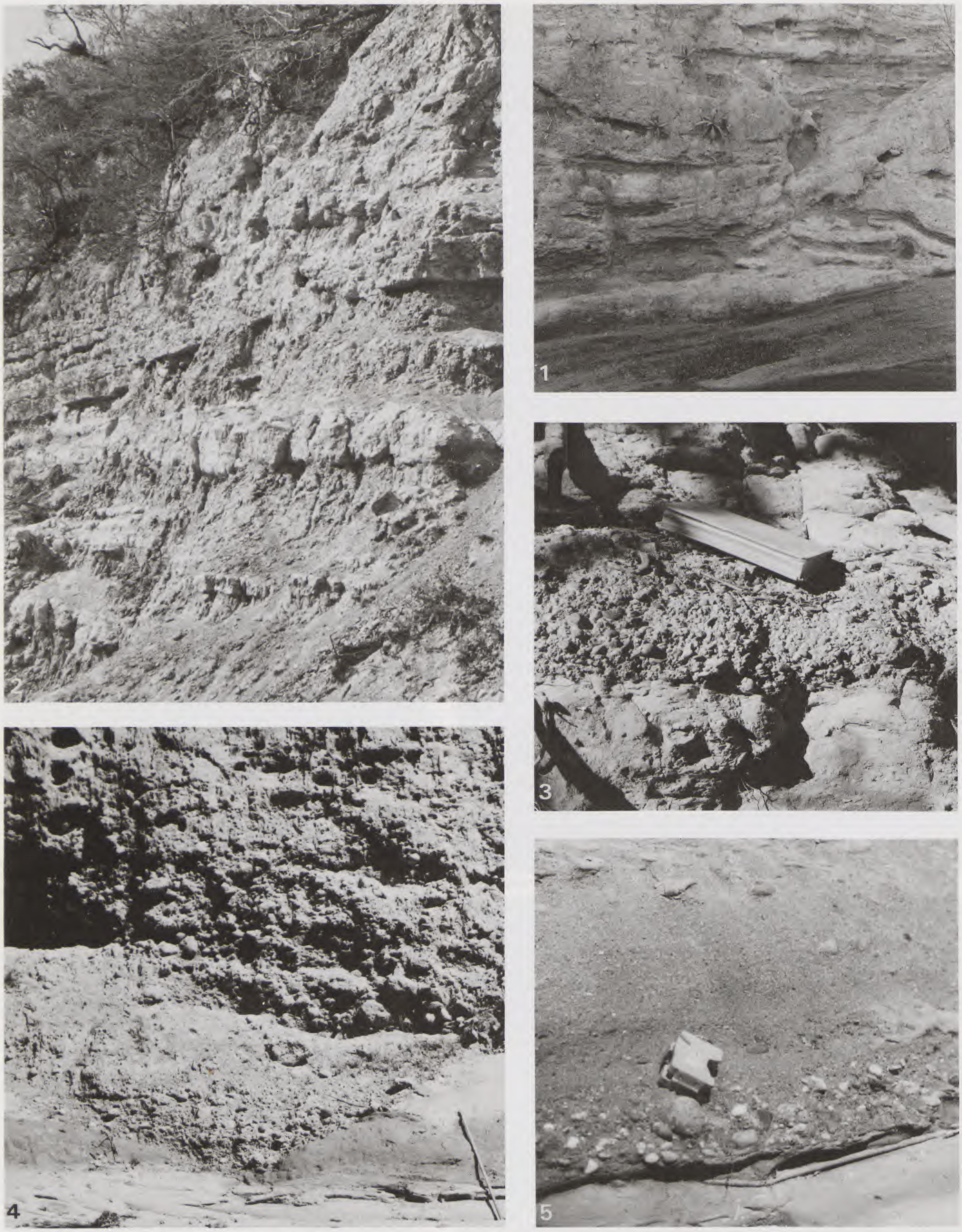
1. Massive to bedded silt and sandy silt at NMB locality 15929. Based on microfossils, the Miocene–Pliocene boundary is placed about 1 m above river level in the smooth, pale-colored silt of the right foreground of the photograph. Silts rich in microfossils and with macrofossils in lenses or scattered throughout cross the boundary with no lithologic change 16
2. Parallel-bedded, calcareous silts alternately richer and poorer in corals at NMB locality 15837. The corals include typical reef dwelling forms like *Montastrea, Solenastrea, Porites* and *Agaricia* as well as typical soft-bottom dwellers such as *Thysanus, Teleiophyllia, Antillophyllia* and *Placocyathus.* In spite of the abundance of true reef corals there is no bioherm development at this outcrop. Reef corals apparently lived in more or less coherent patches spread over a subhorizontal or slightly inclined sea floor. The main limitation to the formation of bioherms seems to have been the scarcity of hard substrate and the existence of stress conditions, perhaps due to high silt influx. Soft-bottom dwellers can, on the other hand, flourish under such conditions. The coral development here is best described as biostromal 13, 16

3, 4. A large lens of massive coral heads at NMB locality 15855. Note 1 m scale. Many of the coral blocks are overturned and broken, suggesting downslope movement, perhaps in a sediment slide. This is almost certainly a slumped mass. Above and below it the bedding is relatively distinct. Many of the broken, branching colonies still show considerable coherence with the broken pieces in close proximity to each other. This either means only a small amount of total movement, or protection during movement within a considerable mass of sediment. The larger heads could have collapsed in place and then could have been moved in the whole sediment slide. 3, upper center—*Montastrea* sp. (inverted); left (inverted) and right (smooth surface by measuring rule)—massive *Goniopora jacobiana*; Lower center—branching *Goniopora* sp. 4, the top of the picture has flat-lying fragments of *Stylophora*; upper left—ends of branches of a single colony of thinly branched poritids; center left—thicker branches of *Goniopora* sp. 12, 13, 16

5. Sand in the lower part of the Gurabo Formation at NMB locality 16170. Burrows with diameters up to several cm are very common at this level. Many are wholly or partly infilled with broken shell fragments and tests of *Amphistegina* 12, 16







EXPLANATION OF PLATE 3

RÍO GURABO

Mao Formation

Figure	Page
1. The youngest outcrops of the Mao Formation on the Río Gurabo are at NMB locality 16119, 900 m above the base of the stratigraphic column. They consist of channeled sands and conglomerates with common contorted slump masses of silt. Text-figure 13 shows some of the depositional patterns observed at this level	14–17
2. A high cliff section at NMB locality 16093, showing interbedded calcareous silty clays and indurated calcarenites. Some of the harder beds contain coral debris and may be conglomeratic. The fine-grained interbeds have an open-marine, reltively deep-water foraminiferal fauna	15
3. Conglomerate with a coarse sand matrix at NMB locality 16042. Pebbles up to 10 cm in diameter occur with fragments of branching corals in a bed that varies in thickness from 10 cm to 40 cm. This bed is in a series of deep-water silts with influxes of terrigenous and bioclastic debris (see Text-fig. 12)	14–16
4. Pebble-filled channel cut into underlying foraminiferal silt and taken as the base of the Mao Formation, at NMB locality 16011. Conglomerates and cross-bedded, coarse sands follow above	14, 16
5. Badly sorted, channeled conglomerate marking the base of the Mao Formation at NMB locality 15997. Pebbles are of melanocratic igneous rocks and quartz. The bed passes up into a pebbly grit with scattered silt clasts	14, 16

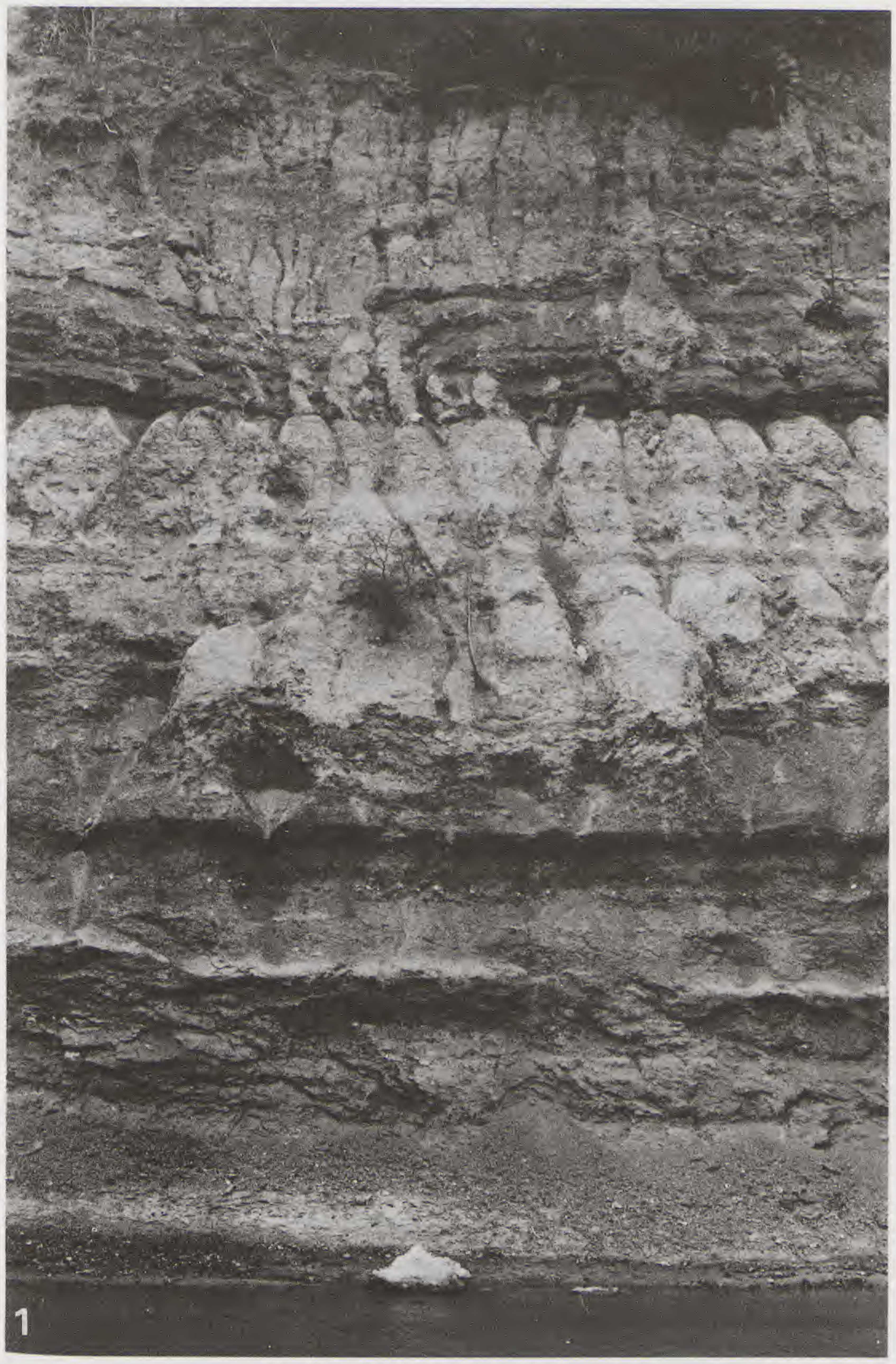
EXPLANATION OF PLATE 4

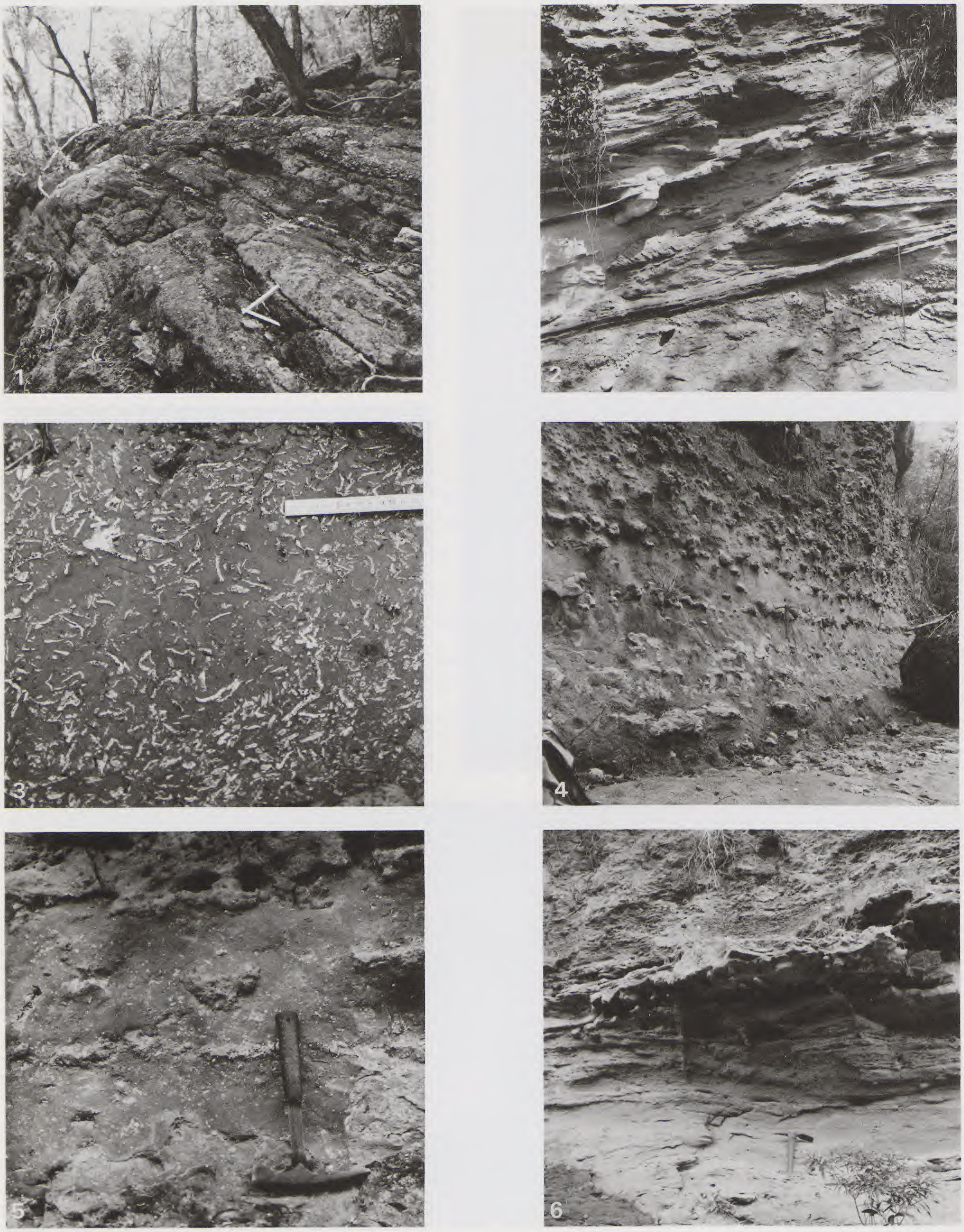
RÍO CANA

Arca patricia beds

Figure Page

1. Left bank cliff with *Arca* beds close to NMB locality 17000 and section shown in Text-figure 18. Interbedded sands and silts with several lignitic clays and with the individual shells of the lowest *Arca* bed shown in Text-figure 18 clearly visible as white spots one-third of the way up the outcrop 20
2. NMB locality 16841. Shell bed packed with *Arca patricia,* many specimens having articulated valves. Each arm of scale is 20 cm . . 22
3. Conglomerate with *Arca* shown in Text-figure 17a. Collections from NMB localities 16839 and 16986 were taken in the shell-packed silt above 22
4. Rhythmic sequence of *Arca* beds shown in Text-figure 17d, where the succession of lignitic clays, dark silts and shell beds is shown graphically. This view shows NMB localities 16848 to 16850 and 16992. Scale is 1.2 m long 20, 22





EXPLANATION OF PLATE 5

RÍO CANA

Cercado, Gurabo and Mao formations

Figure | Page

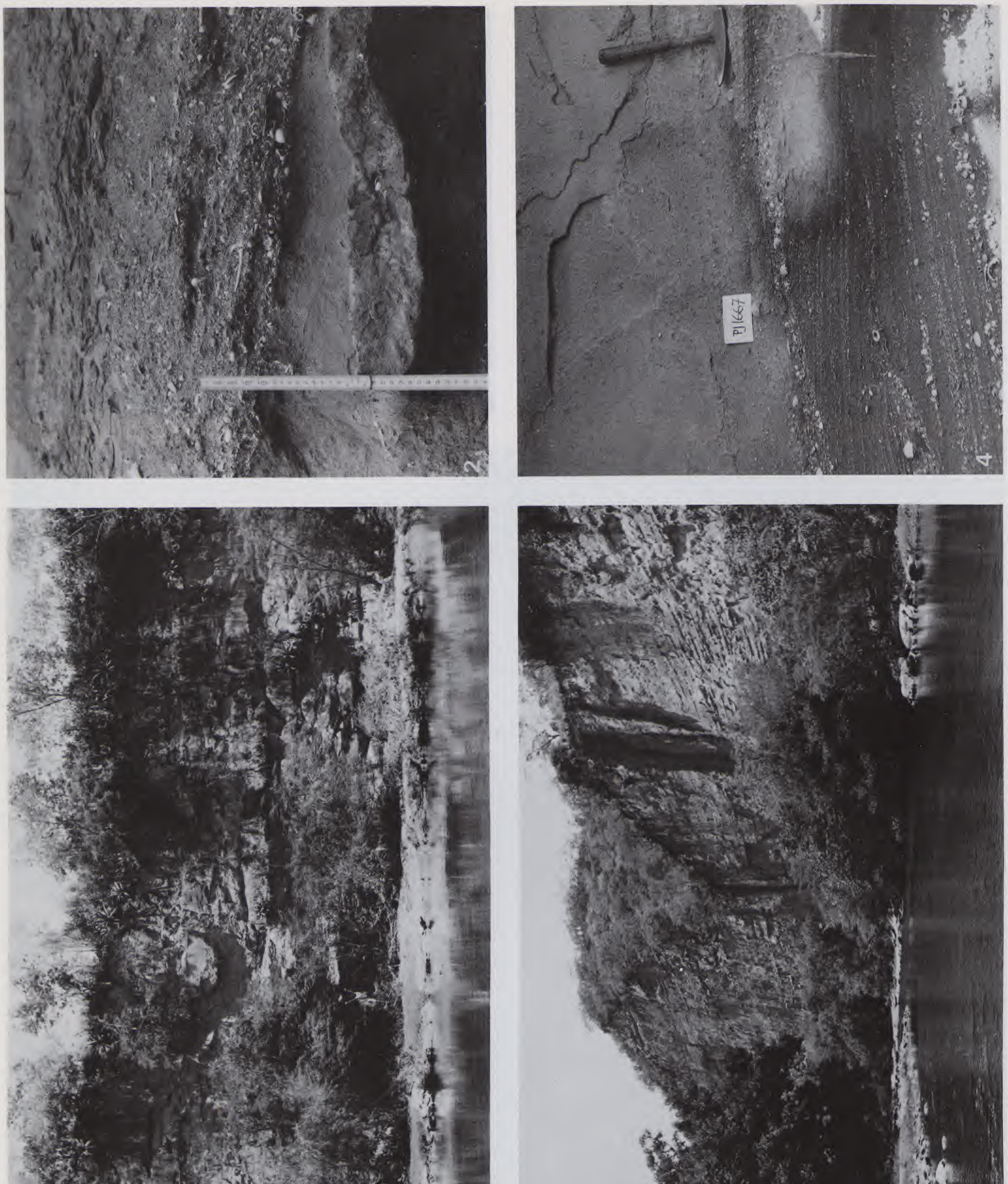
1. Foreset beds in the Mao Formation in a left bank cliff at 630 m above the base of the stratigraphic column shown in Text-figure 15. These steeply-dipping beds of conglomerate and coarse sands are shown on the right side of Text-figure 19. Each arm of the scale is 20 cm 21, 22
2. NMB locality 17015 in the Gurabo Formation. Cross-bedded sands discordantly cutting a pebbly grit that shows load cast structures penetrating the clayey silts below. The 1 m straight part of the rule stands in front of the right load structure 22
3. Right bank cliff at NMB locality 16963 in the Gurabo Formation. Silt packed with flat fragments of either *Helioseris* or *Leptoseris* ... 20
4. Right bank cliff at NMB locality 17007 in the Gurabo Formation. Silt with prominent calcareous concretions typical of the middle part of the Río Cana section. Coral debris (including the forms seen in Plate 5, figure 3) is common together with benthic foraminiferal faunas and scattered molluscs. Pick handle is 40 cm long 20, 22
5. Approximately at NMB locality 16960 near the base of the Gurabo Formation. Calcareous sandy silt with frequent harder concretionary layers. The white spots are tests of *Sphaerogypsina*. This is a very characteristic foraminiferal species in these shallow marine beds, which are also rich in bryozoa, molluscs and corals 22
6. Right bank cliff shown schematically in Text-figure 17c. Festoon cross-bedded sands, the upper portion of which are thick with interlocking burrows of *Callianassa*-type that are up to 5 cm in diameter. Immediately above is a molluscan-rich silt with a layer of *Arca* shells at its base 20, 22

EXPLANATION OF PLATE 6

RÍO CANA

Mao Adentro Limestone

Figure	Page
1. Northern end of Río Cana gorge. Exposure on left bank at NMB locality 16884, close to NMB locality 17023. This is near the top of the limestone sequence. Broken and transported corals, both massive and branching forms, indicate movement downslope. The beds are irregular and seem to show channeling consistent with deposition on a slope. The foraminiferal fauna has a high ratio of planktic to benthic foraminifera, and suggests a water depth greater than 100 m—and perhaps twice that amount	21, 22
2. The base of the limestone at the south end of the gorge. This is shown schematically in Text-figure 20, where the NMB localities are also given. Sands, heavily burrowed at the top, are followed by pebbly calcarenite which is not rich in corals but is followed by a carpet of branching poritids that forms the base of the coral-rich section	21, 22
3. View into the gorge slightly downstream from the section shown in Plate 6, figure 2. Dr. Geister (written commun., 1984) writes: "Limestone massive to bedded (beds 0.5 to 1.5 meters), very rich in branching corals (*Stylophora, Porites*). Some massive corals (*Montastrea*) and platy corals (*Goniopora, Leptoseris*). Many if not most of the corals do not seem to be in place and were probably transported downslope. Corals badly preserved due to diagenetic alteration"	21, 22



EXPLANATION OF PLATE 7

Río Mao

Maury's Bluffs 2 and 3

Figure | Page

1, 2. Maury's Bluff 2 on the left bank of the Río Mao 32

1. General view of silts with harder parts standing out due to secondary concretions. A schematic view of the whole cliff is given in Text-figure 31.
2. Detail of shell bed (NMB loc. 16930) where this comes down close to river level towards the eastern end of the left bank cliff. Oriented shells of *Dentalium* are very conspicuous. The matrix is packed with *Amphistegina.*

3, 4. Maury's Bluff 3 at the eastern (downstream) end 31, 32

3. The high cliffs are composed of sands, partly flat-bedded and partly cross-bedded, with the bedding often picked out by calcareous concretions. The cliffs descend towards the east where they are schematically shown in Text-figure 33.
4. Detail of NMB locality 16913, showing cross-bedding picked out by small molluscs and by countless shells of *Amphistegina.* All shell horizons lens rapidly. The matrix is calcareous, silty sand. The complete absence of planktic and deeper-water benthic foraminifera and of calcareous nannofossils attests to the shallow water, inshore nature of the beds.

EXPLANATION OF PLATE 8

Río Mao and Río Yaque del Norte

Figure — Page

1. General view of Maury's Bluff 1 on the left bank of the Río Mao. A microfossil sample (from NMB loc. 17175) shows a slightly more open marine assemblage than is found in Bluffs 1 and 2 .... 25, 31
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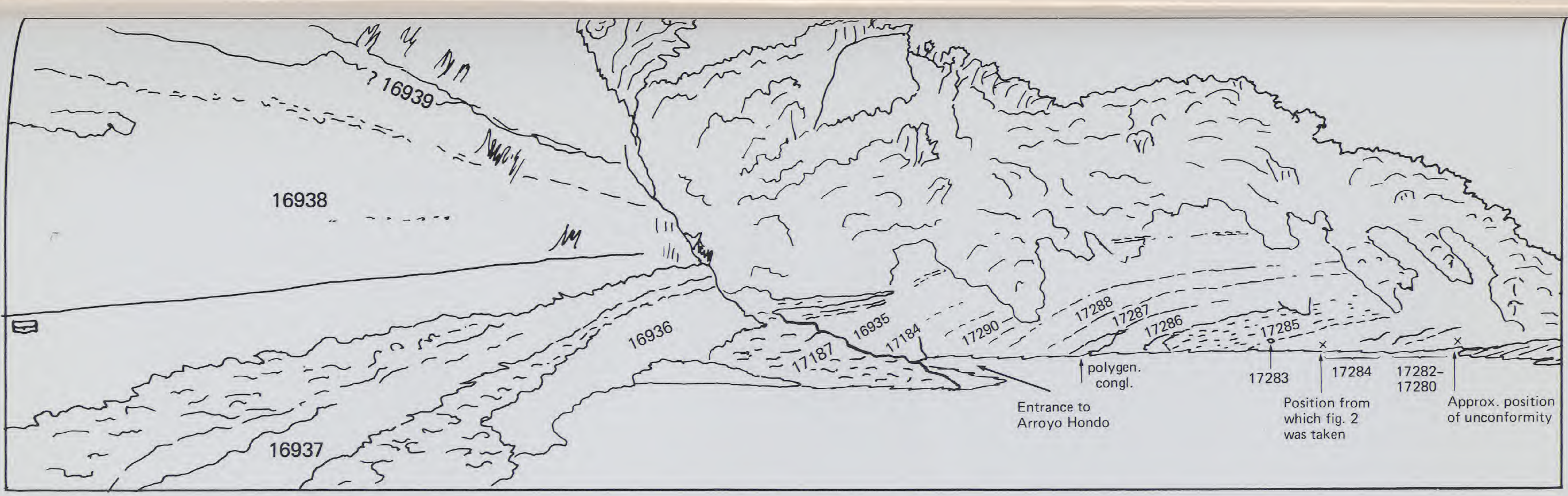
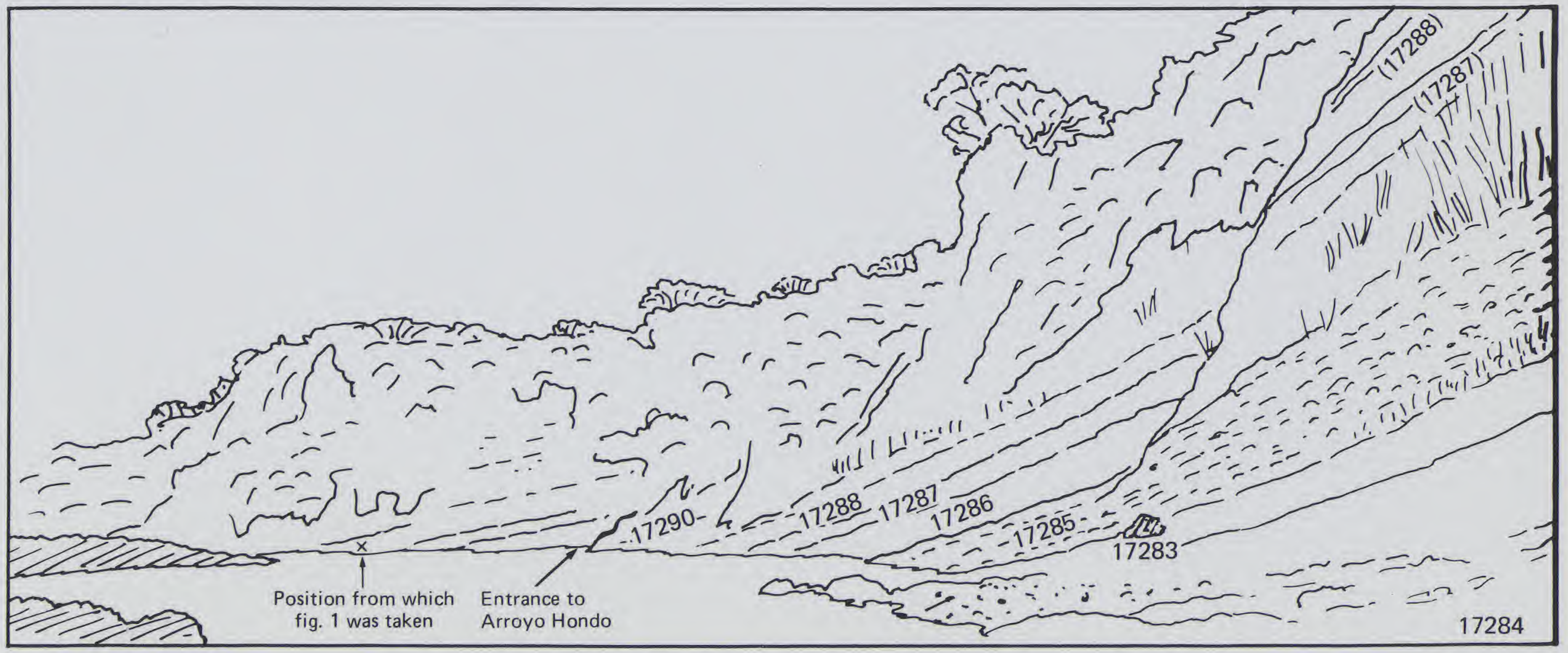




EXPLANATION OF PLATE 9

Río Yaque del Norte
Baitoa Formation

Panoramic views of the hypostratotypic section of the Baitoa Formation upstream from López below the confluence of Río Bao and Río Yaque del Norte. . p. 39

These photographs were taken in 1980 just after Hurricane Allen had made it necessary to let unusually large amounts of water down the river from a dam situated upstream. This removed a great deal of vegetation from the lower part of the cliffs making the section better exposed than it had been for years, and allowing us to measure the section and to collect extensively from it (see Text-fig. 25)

1. View upstream. The gorge in the center of the photograph is the entrance of the Arroyo Hondo indicated on the sketch (above).
2. View downstream. The mouth of the Arroyo Hondo is again indicated on the sketch.

Date Due

APR 30 1995

EXPLANATIONS OF FIGURES

IN POCKET INSIDE BACK COVER

NOTE: These captions are updates of those printed directly on the figures. They have been printed on paper that has a PERMANENT adhesive backing and may be peeled off and stuck down on the figures, or in any other desired location.

Text-figure 4.—Map and columnar section of Río Gurabo (area 2 of Text-fig. 3), showing geographic and stratigraphic positions of NMB collecting localities. Open squares or rectangles represent samples collected for microfossils and lithologic analyses; black circles represent samples collected for macrofossils.

Text-figure 5.—Map of Río Gurabo (area 2 of Text-fig. 3), showing geographic positions of selected TU and USGS collecting localities.

Text-figure 6.—Columnar section for Río Gurabo, showing lithologies and ages.

Text-figure 15.—Map and columnar section of Río Cana (area 1 of Text-fig. 3), showing geographic and stratigraphic positions of NMB localities, and geographic positions of TU localities. Open squares represent NMB localities collected for microfossils and lithologic analyses; black circles represent NMB localities collected for macrofossils. A = *Arca* beds. Lithologies are portrayed as in Text-figure 16.

Text-figure 16.—Columnar section for Río Cana, showing lithologies and ages. A = *Arca* beds.

Text-figure 21.—Map of Río Yaque del Norte (area 6 of Text-fig. 3), showing geographic positions of NMB, TU, and USGS collecting localities. Open squares represent NMB localities collected for microfossils and lithologic analyses; black circles represent NMB and TU localities collected for macrofossils. See Text-figures 25 through 28 for details of localities on the southern portion of this map area.

Text-figure 25.—Columnar section of cliff exposures on Río Yaque del Norte north of Baitoa, showing lithologies and stratigraphic positions of NMB collecting localities (see Text-fig. 21 for geographic positions of these localities). See also Plate 9.

Text-figure 29.—Map of Río Mao (area 3 of Text-fig. 3), showing geographic positions of NMB, TU, and USGS collecting localities. Open squares represent NMB localities collected for microfossils and lithologic analyses; black circles represent NMB localities collected for macrofossils. Geographic positions of Maury's Bluffs 1, 2 (see Text-fig. 31), and 3 (see Text-fig. 33) are also shown.

Text-figure 34.—Map of the central portion of Río Amina (area 4 of Text-fig. 3), showing geographic positions of NMB, TU, and USGS collecting localities. Open squares represent NMB localities collected for microfossils and lithological analyses; black circles represent NMB samples collected for macrofossils.

Text-figure 4 Map and columnar section of Rio Gurabo showing topographic and stratigraphic position of NMB localities.

RIO GURABO

Text-figure 5 Map of Rio Gurabo showing position of USGS and TU localities.

Text-figure 6 Columnar section of Rio Gurabo giving lithologies and age.

Text-figure 15 Map and columnar section of Rio Cana showing topographic position of NMB, USGS and TU localities and stratigraphic position of NMB localities.

Text-figure 16 Columnar section of Rio Cana giving lithologies and age.

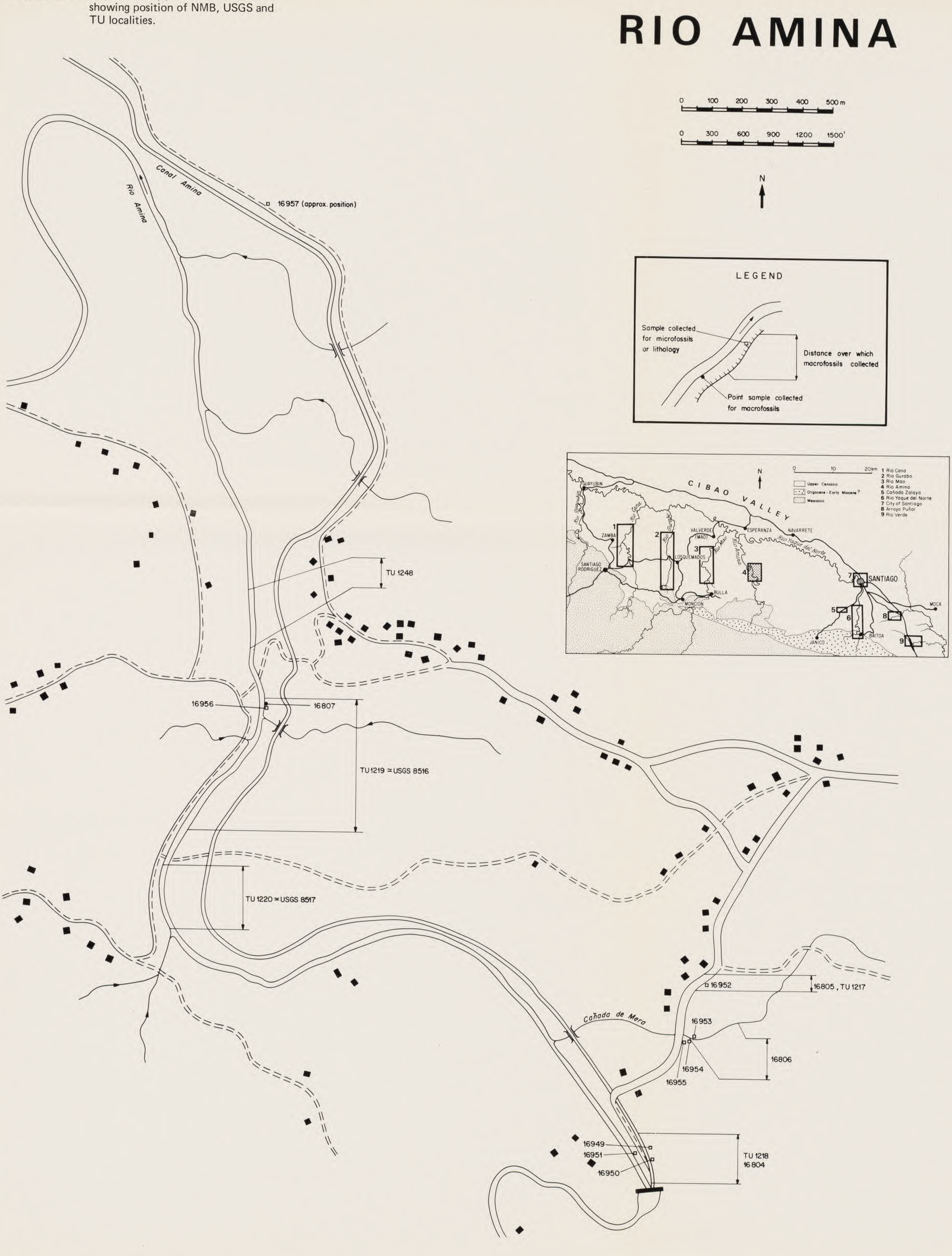
Text-figure 21 Map of Rio Yaque del Norte showing position of NMB, USGS and TU localities.

RIO YAQUE DEL NORTE

Text-figure 25 Columnar section of cliff exposures on the Rio Yaque del Norte north of Baitoa giving lithologies and stratigraphic position of NMB localities.

Text-figure 29 Map of Rio Mao showing position of NMB, USGS and TU localities.

Text-figure 34 Map of central portion of Rio Amina showing position of NMB, USGS and TU localities.



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